METHODS AND COSTS OF SINKING A SHAFT THROUGH A FRACTURED, WATER-BEARING FORMATION AT FRIEDENSVILLE, PA.

BY WARREN HASTINGS, F. J. KANE, AND F. D. WRIGHT

* * * * * * * * * * **Information Circular 7680**

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METHODS AND COSTS OF SINKING A SHAFT THROUGH A FRACTURED, WATER-BEARING FORMATION AT FRIEDENSVILLE, PA.

by

Warren Hastings,[1] F. J. Kane,[2] and F. D. Wright[3]

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INTRODUCTION AND SUMMARY

This paper describes the methods and costs, in units of labor and materials, of sinking a 7 compartment vertical shaft 1,261 feet through a fractured, water-saturated formation. The shaft, designed for hoisting 2,500 tons a day, is at Friedensville, Lehigh County, Pa., approximately 6 miles south of Allentown and Bethlehem. It was sunk by the E. J. Longyear Co. under contract to the New Jersey Zinc Co.

Preparation for shaft sinking was begun July 1, 1947, and sinking was completed August 18, 1952. A total of 604,858 man hours was required to sink the shaft.

From the very beginning of the operation, an extensive grouting and concreting program was conducted to seal the shaft from water.[1/] Approximately 33 miles of test drilling, 200,000 cubic feet of grout, and 8,800 cubic yards of concrete were required to complete the shaft. Despite elaborate precautions while sinking, the shaft was flooded on 3 different occasions from fractures in the shaft bottom and once from a fracture in the 400-foot level.

Throughout the entire sinking, the measured pressure of water encountered in test holes was within a few pounds of the theoretical hydrostatic pressure from the top of the water table. Water pressure near the bottom of the shaft was 535 p.s.i. To control water at such high pressures required ingenuity, careful planning, and competent miners.

ACKNOWLEDGMENTS

The authors are indebted to the officials of the New Jersey Zinc Co. for their cooperation in making these data available for publication. Most of the drawings in this circular were made by M. W. Lanning, mining engineer, New Jersey Zinc Co. Much of the following information was included in a previous publication of which R. L. Loofbourow, manager, Mining Division, E. J. Longyear Co., was coauthor.

PURPOSE OF SHAFT

The most important known zinc deposits in Pennsylvania are near Friedensville. Zinc minerals were discovered on the farm of Jacob Ueberroth early in the 19th century. Subsequently, several mines were developed and operated until 1893, when the excessive cost of pumping water caused the last mine to close. There has been no production since that time.

1/ Wright, F. D., Loofbourow, R. L., and Kane, F. J., Water Problems in Shaft Sinking at Friedensville, Pa.: Min. Cong. Jour., vol. 37, No. 11, November 1951, pp. 25-29.

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The New Jersey Zinc Co. explored the area in 1914 and 1915 and began to pump out the old workings of the New Hartman mine. Conditions brought about by World War I interfered, and the work was discontinued.

Since that time, a zinc ore body called the New Hartman ore run has been proved by additional exploration with diamond-core drilling and churn drilling. To exploit this and other possible ore deposits in the area, the New Jersey Zinc Co. in 1947 contracted with the E. J. Longyear Co. to sink the Friedensville shaft.

GEOLOGY

The Friedensville zinc deposits occur in the Beekmantown formation, Ordovician system. The predominant country rock is limy dolomite, with local zones of limestone. Thin, ribbony beds of limestone and dolomite are interstratified with more massive beds up to 10 feet thick, with breccia zones and with silica sand beds. Flint and chert lenses occur throughout the section. The dolomite, because of silicification, is harder than the usual dolomite.

The strata have been folded and faulted. They are cut by veins of quartz and calcite and by two principal jointing systems roughly at right angles to each other and to the bedding. The water table is 11 to 20 feet below the surface, and the formation has been oxidized and decomposed, in part at least, to a depth of many hundred feet. A description of the character of the formation through which the shaft was sunk is given in table 1.

TABLE 1. - Character of the formation around shaft

Depth below collar, feet	Description
0 - 60	Overburden
60 - 150	Comparable to rough masonry wall with bedding-plane fractures dipping to south and numerous cross fractures breaking formation into roughly rectangular blocks, with clay occurring in seams.
150 - 350	Very badly fractured and decomposed. Many clay-filled cavities.
350 - 400	Comparatively tight.
400 - 850	Less badly fractured than near top, but elaborate test drilling and grouting required to seal shaft.
850 - 1,210	Comparatively tight.
1,210 - 1,261	Fractured with water at 535 p.s.i.

The principal ore deposits lie parallel to the bedding planes and have fairly regular strikes and dips. The boundaries of the ore bodies are cleancut in places, but generally the mineralization fades gradually into the country rock. Miller[2/] states: "This ore was in part the filling of the original narrow openings between the beds, but mainly the replacement of the adjacent limestone. Joints, generally perpendicular to the beds, likewise furnish places for ore deposition."

2/ Miller, B. L., Lehigh County, Pa., Geology and Geography: Pennsylvania Geol. Survey, 4th series, Bull. C39, 1941, pp. 326-54.

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The New Hartman ore run is a lens of varying thickness that dips 23° to the south. Sphalerite, intimately associated with pyrite and marcasite, is the principal ore mineral.

PREPARATION FOR SHAFT SINKING

The Friedensville shaft is south of the New Hartman ore run and is in the hanging wall of the deposit. After the water table has been lowered, the initial development plan is to crosscut and drift 2,600 feet on the 400-foot level and raise to the old workings in the abandoned New Hartman mine.

The principal factor in selecting the shaft site was that test holes indicated the country rock was somewhat less fractured and decomposed at this location than at any other in the vicinity of the ore body.

The small amount of surface excavation and leveling required in preparation for shaft sinking was done with a bulldozer. A settling pond and ditch were dug to drain the water pumped from the shaft into Saucon Creek, and a weir was built at the intake of the pond to measure the quantities of water pumped.

A 50-foot temporary headframe (see fig. 1) constructed of 10- by 10-inch timbers, equipped with two 6-foot sheaves and an air-operated dump door, was installed for sinking the shaft. Broken rock was hoisted in a 50-cubic foot bucket, attached to a safety crosshead and a 1-inch cable; discharged through a chute directly into trucks; and then used for fill in the plant area.

Power was delivered at 66,000 volts to a temporary 15,000 kv.-a. transformer station, later replaced by a permanent station of 90,000 kv.-a. capacity, which in turn delivered power at 2,300 volt 60 cycles with further reduction to 440 volts for operation of the compressors, pumps, and miscellaneous tools that were used during sinking.

SURFACE PLANT

The following temporary buildings and equipment were used while the shaft was being sunk:

Building	Equipment
Field office	
Hoist, compressor, and change house	1 350-hp. hoist with rope speed of 1,200 ft. per min. 1 75-hp. hoist. 2 500-cu. ft. compressors. 1 600-cu. ft. compressor. 1 cap-lamp charger.
Carpenter shop	1 power saw, sander.
Repair shop	Bench grinder, bit grinder, pipe threader, arc welder, drill press, and cutoff grinder.
Storage shed	
Magazine for explosives	

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The following additional equipment also was used:

2 coffin hoists (3/4 ton)	1 impact wrench
13 electric sinking pumps (150-1,000 g.p.m.)	2 concrete vibrators
7 air hoists (single and double)	1 portable grinder
6 pneumatic sump pumps	1 wood borer
9 jackhammers	3 grout pumps
4 diamond drills	1 Riddell mucking machine
4 pavement breakers	2 Coppus Ventair blowers (No. 8 and 9)
1 clay tamper	1 Ford pickup truck
	2 dump trucks

After sinking was completed, a permanent headframe (see fig. 2), 132 feet high and weighing 200 tons, was erected on temporary foundations 50 feet east of the shaft and skidded into place on 80-pound rails (see fig. 3) using 2 sets of triple and double blocks threaded with 3/4-inch steel rope attached to 2 winch trucks. The back legs of the headframe were supported on mine car trucks and pulled by a third winch truck.3/ This headframe will be completely enclosed by sheeting, and miners will have access to the shaft collar through an underground passageway from the change room.

Hoisting equipment includes a 300-hp. a.c. man-cage hoist, a 500-hp. a.c. skip hoist, a man cage with a capactiy of 65 men, a counterweight for the man cage, and two 6.5- by 3.7- by 3.9-foot skips, each with a capacity of 6 tons. Both hoists have a rope speed of 900 feet per minute. The man cage is attached to its hoist by a 1-5/8-inch diameter, 6 by 19 plow steel lang-lay rope, the counterweight by a 1-3/8-inch diameter, 18 by 7 nonrotating plow steel rope, and the skips by 1-3/8-inch diameter, 6 by 19 plow steel lang-lay ropes.

One building houses the hoist, compressor, boiler, supply, and change rooms, the blacksmith, carpenter, electrical, and machine shops, a transformer and switchgear station, a dispensary, and the offices.

SHAFT SINKING

Preparation for shaft sinking was begun July 1, 1947. Actual sinking began in February 1948 and ended August 18, 1952. During this period 1,261 feet of shaft were sunk and 945 feet of level and pump stations were excavated.

The shaft walls are supported by steel sets (see fig. 4) spaced 7 feet apart vertically and by a reinforced concrete lining that has a minimum thickness of 24 inches to a depth of 430 feet and a minimum thickness of 12 inches below this point. The shaft is 13 by 20-1/2 feet inside the concrete and is divided into 2 skip compartments, 1 supply-cage compartment, 1 compartment for a counterweight for the cage, 1 for a ladderway, 1 for pipes, and 1 for electric cables. The compartments are separated by heavy wire screens fastened to wall plates and dividers. Guides in each skip compartment are two 80-pound steel rails. The 2 pairs of guides for the supply cage are made of laminated wood 6 by 10 inches in cross section.

Initial station excavations were mined as the shaft was sunk. Level stations were cut on the 400-, 600-, 700-, 800-, 900-, and 1,050-foot levels; pump sations on the 418-, 818-, and 1,068-foot levels; a crusher station at the 1,121-foot level;

3/ Engineering and Mining Journal, 200-ton Prebuilt Headframe Moved Into Position Over Shaft: Vol. 153, No. 12, December 1952, pp. 76-79.

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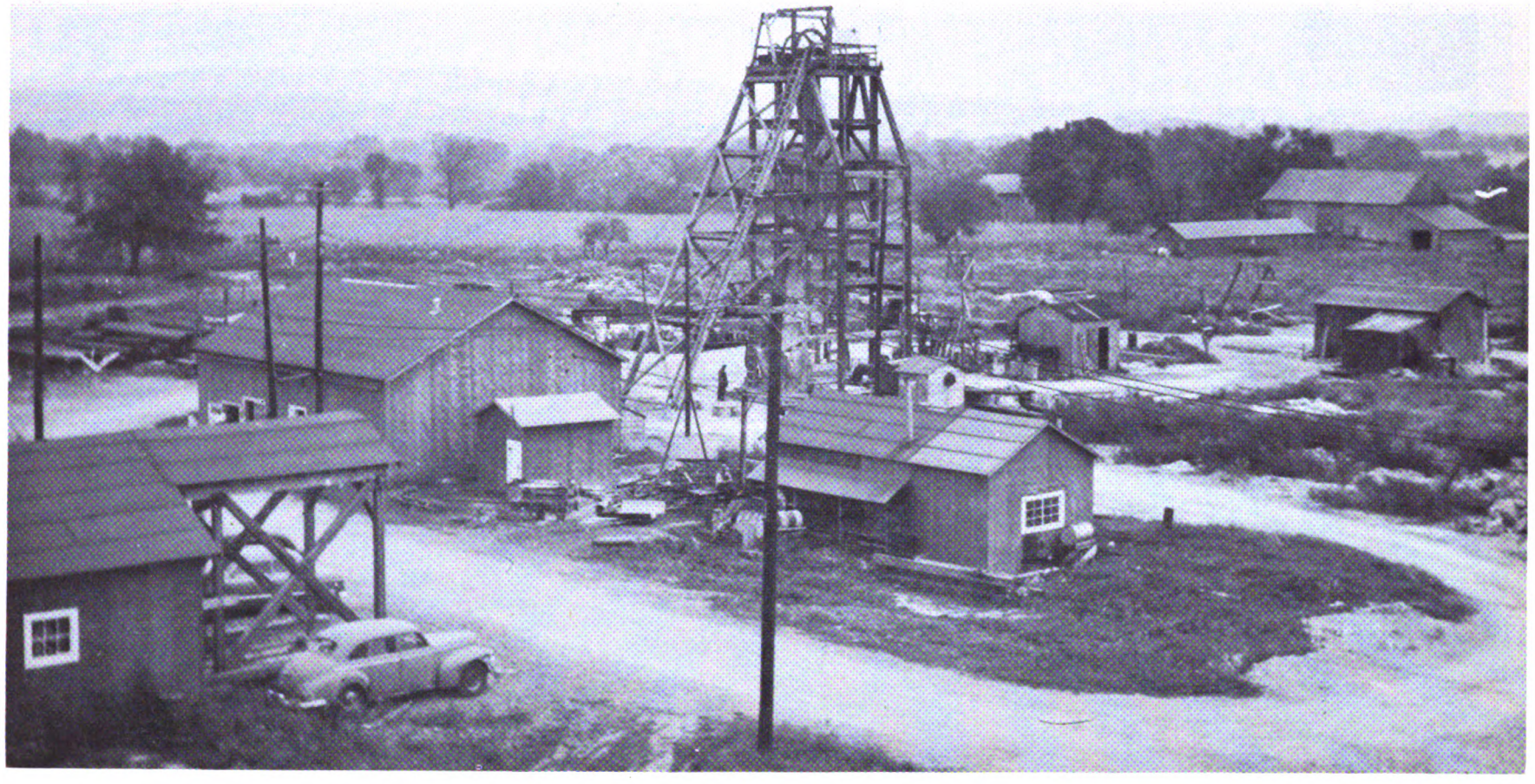

Figure 1. - The temporary headframe used for sinking the shaft.

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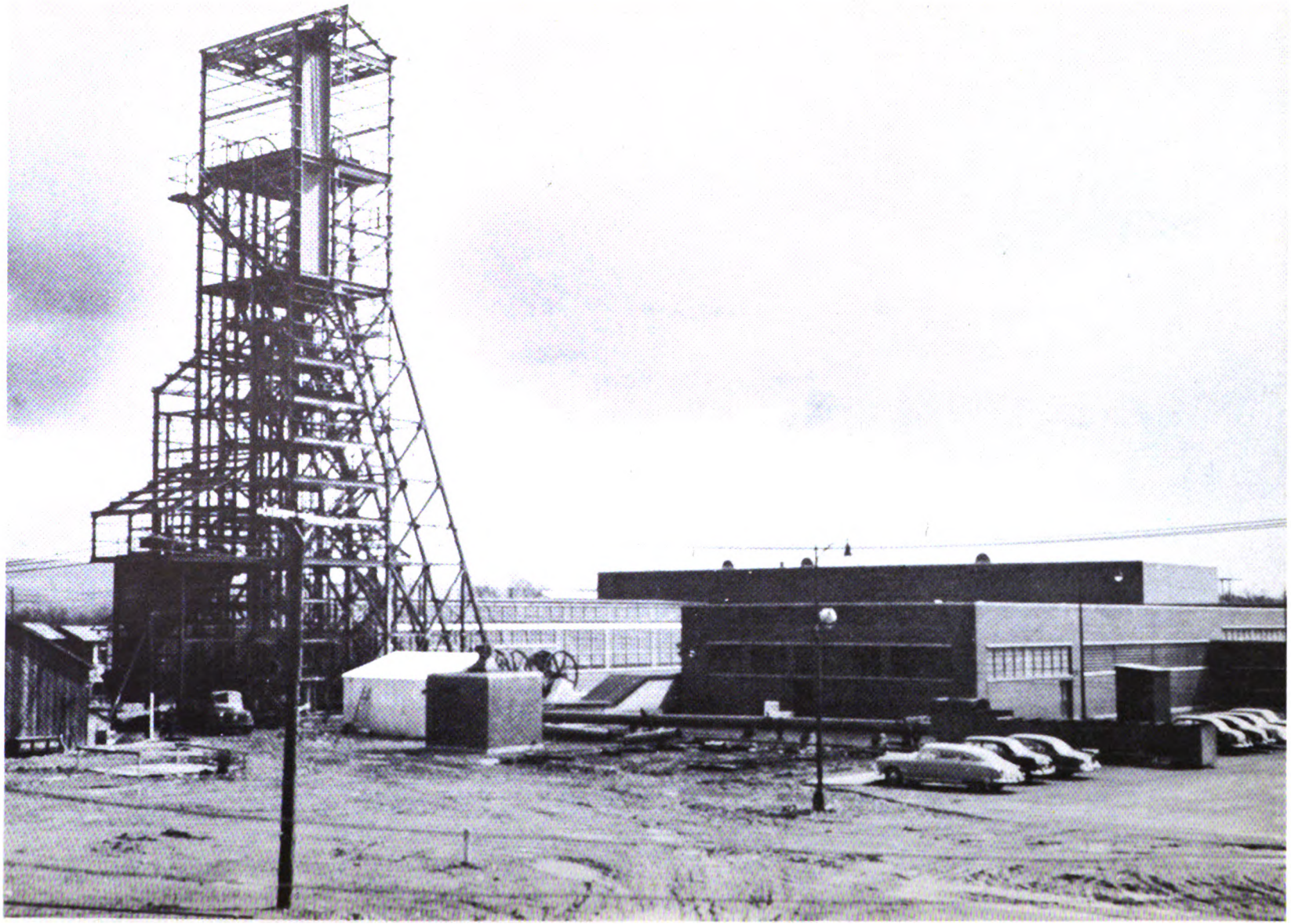

Figure 2. - The permanent headframe.

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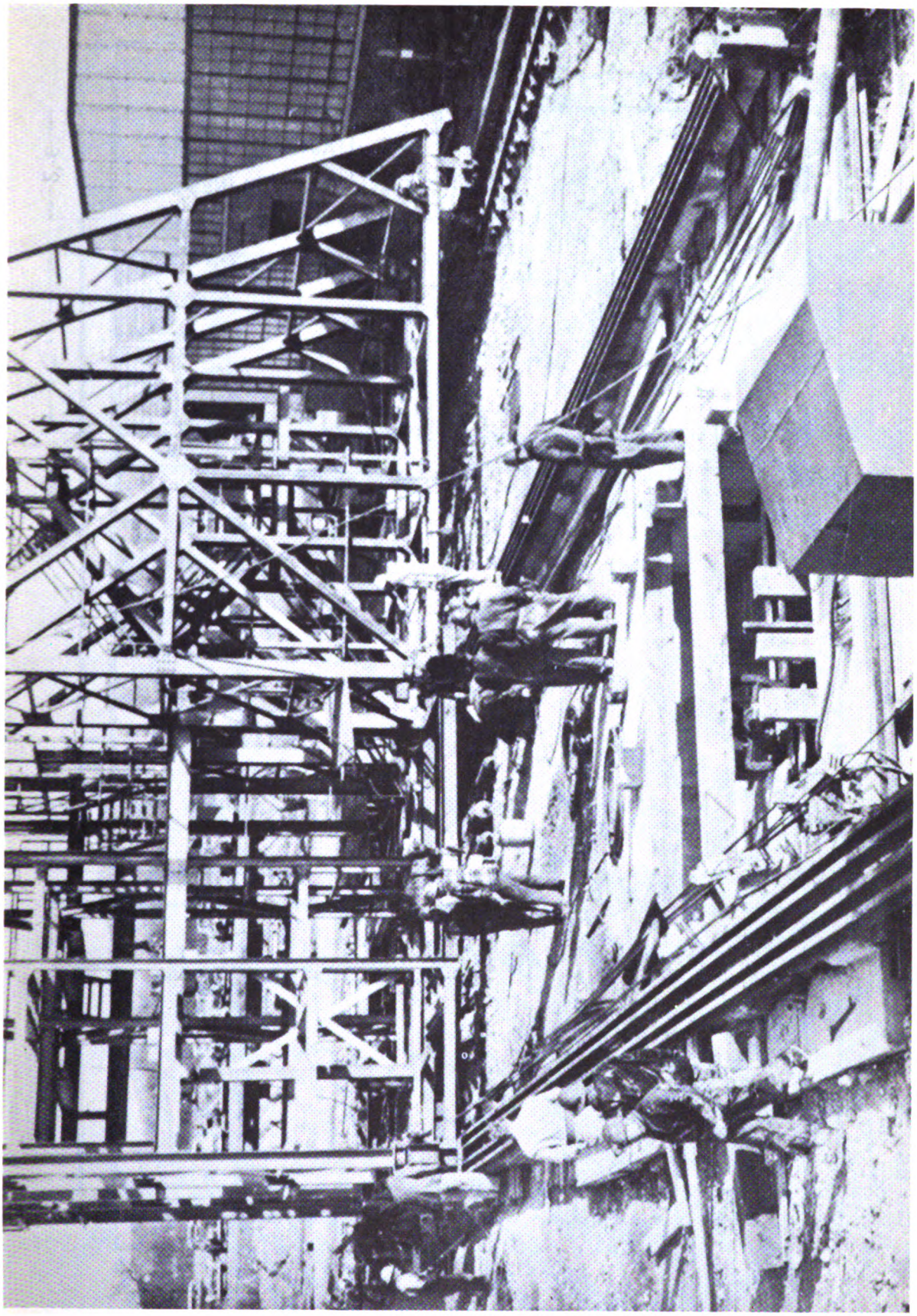

Figure 3. - Moving permanent headframe into position over the shaft.

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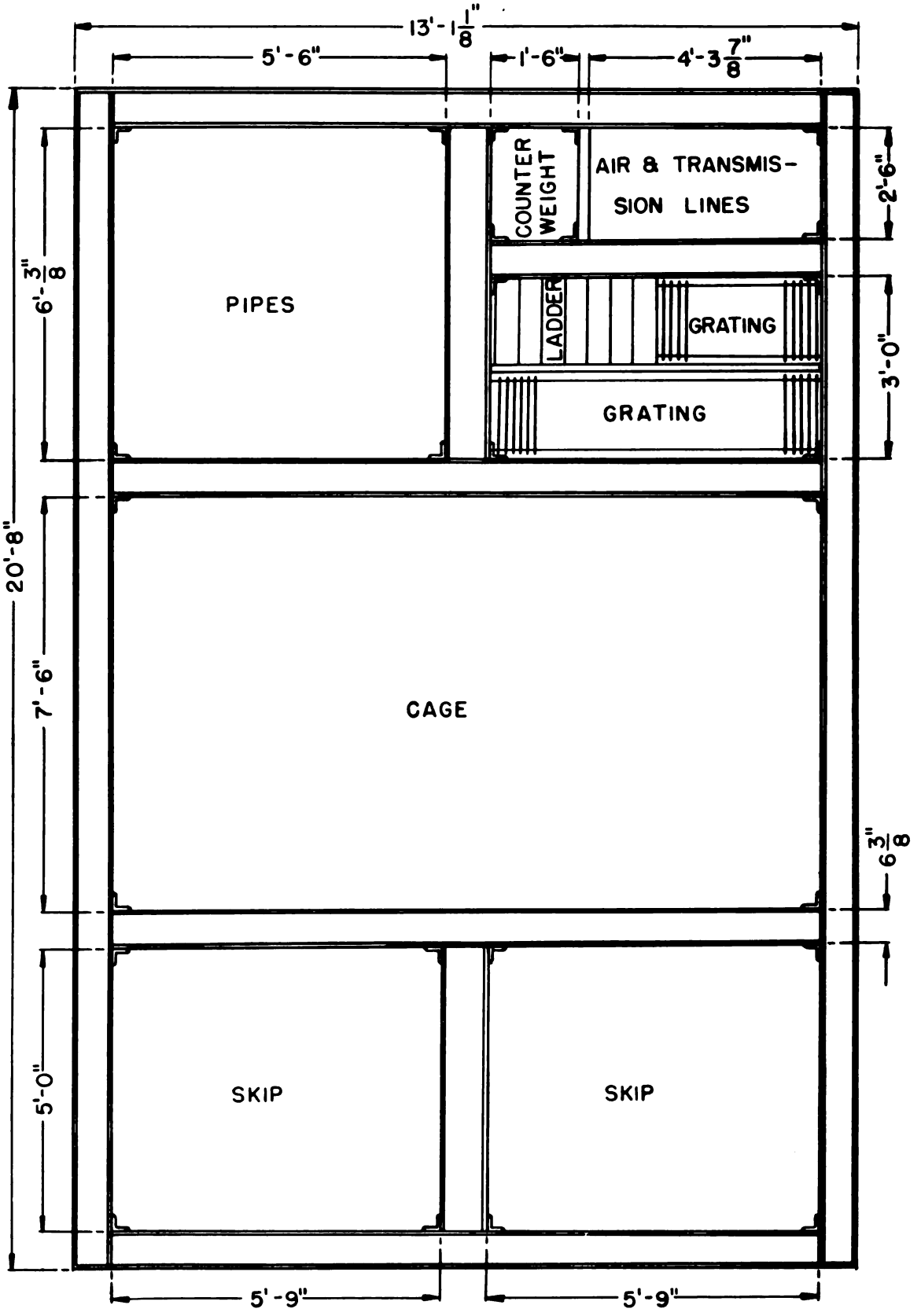

Figure 4. - Steel shaft set.

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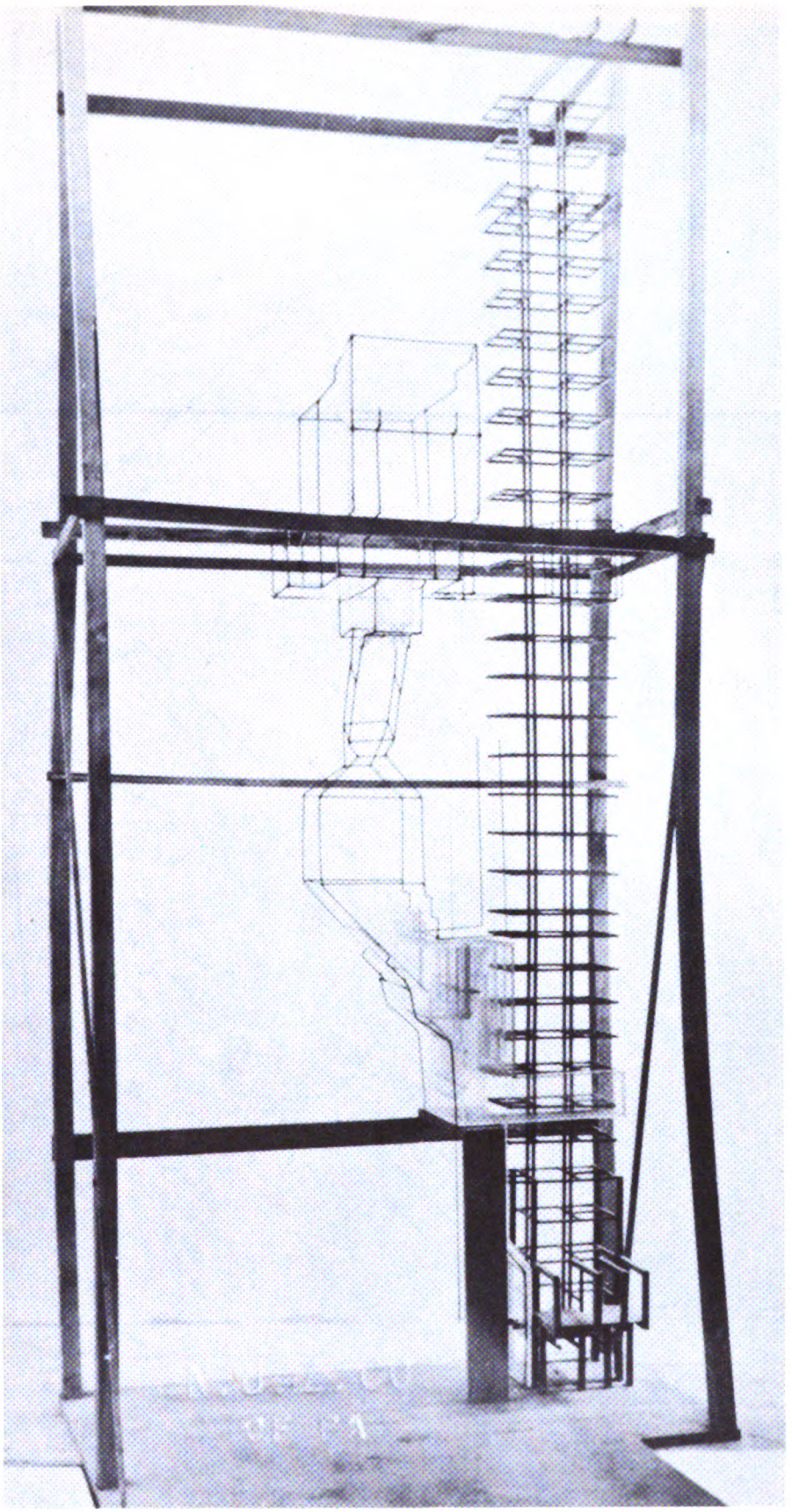

Figure 5. - Model of the underground crusher station and loading pocket.

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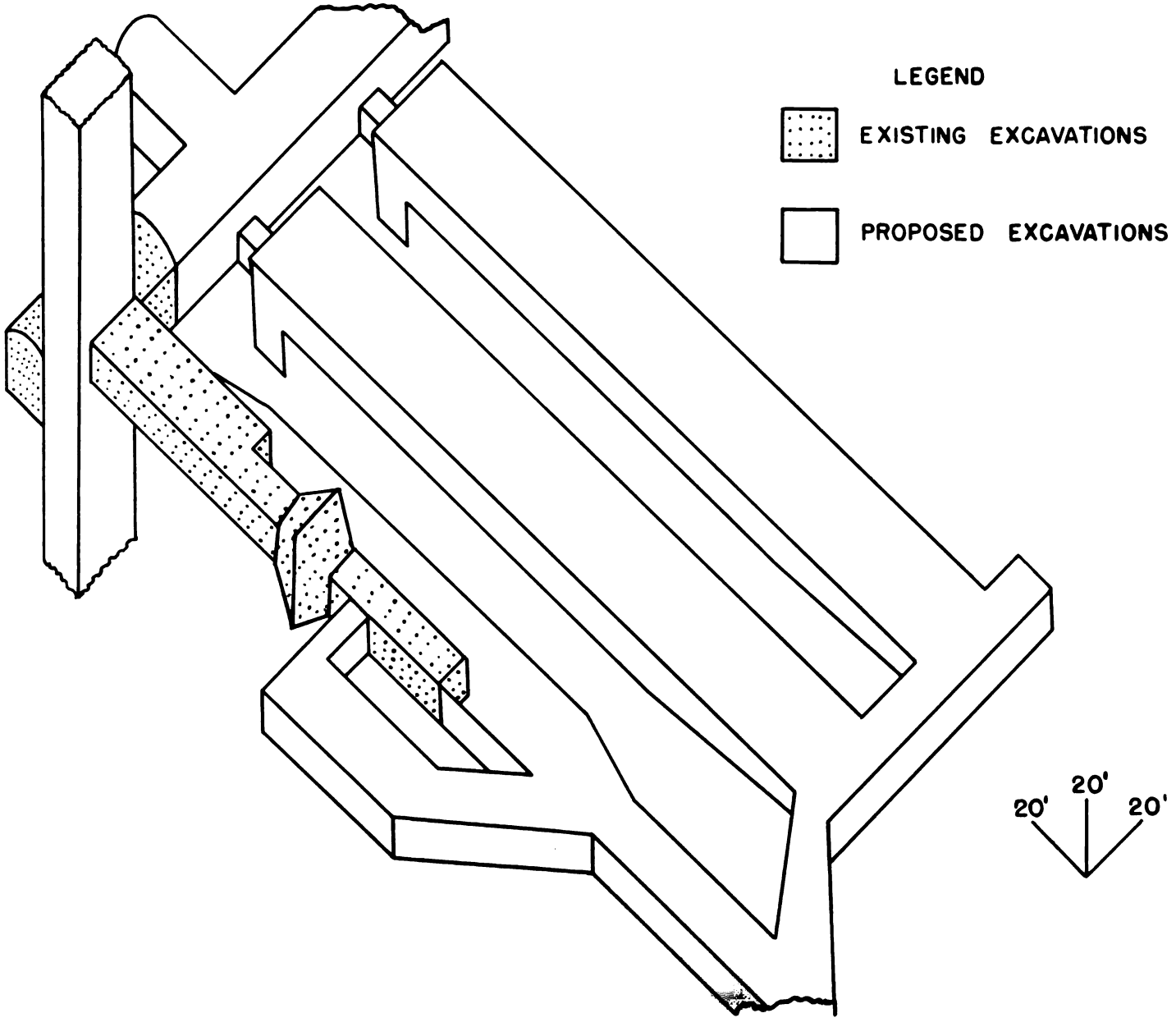

Figure 6. - 400-foot level station and 418-foot pump station.

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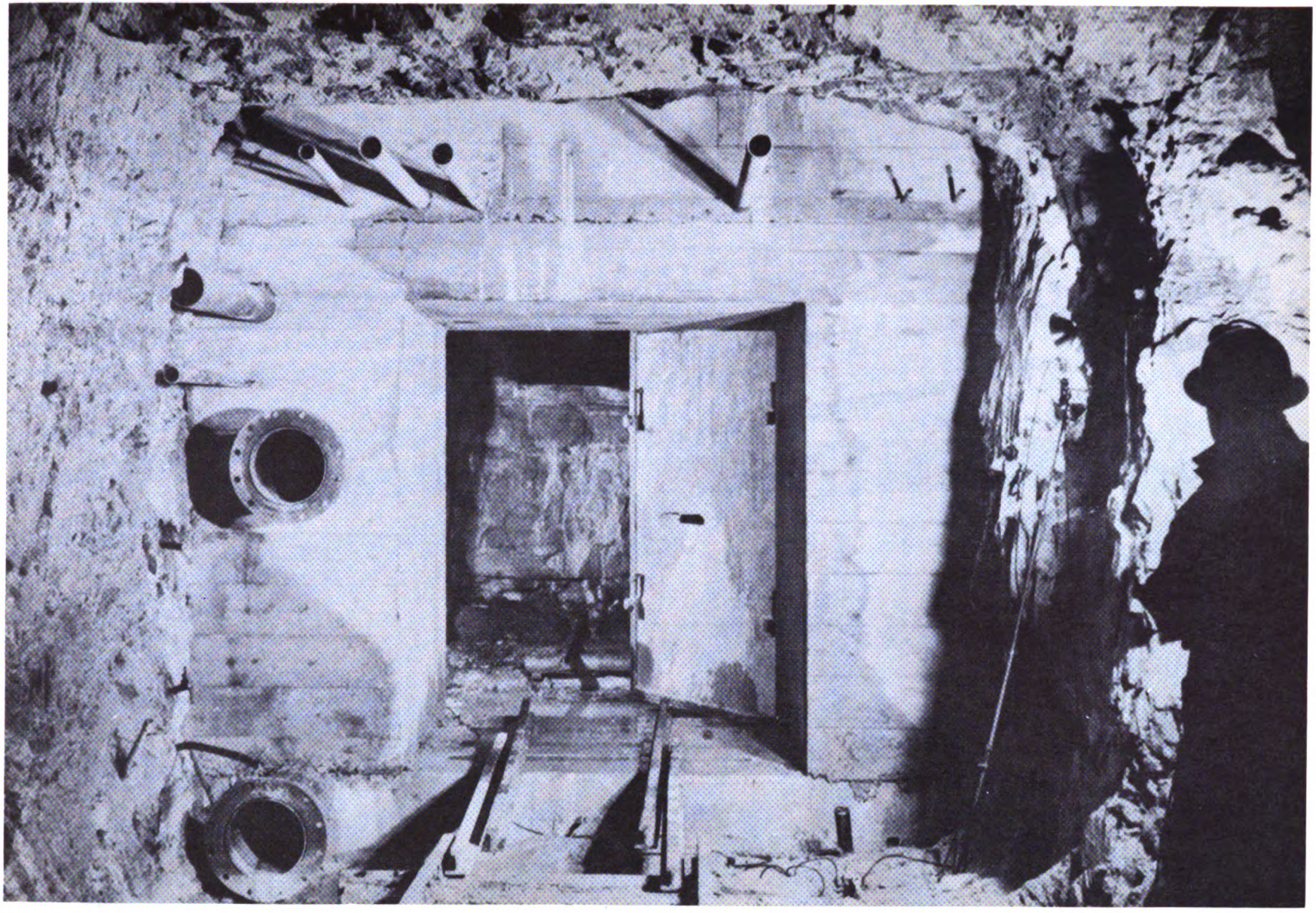

Figure 7. - Concrete bulkhead on the 400-foot level.

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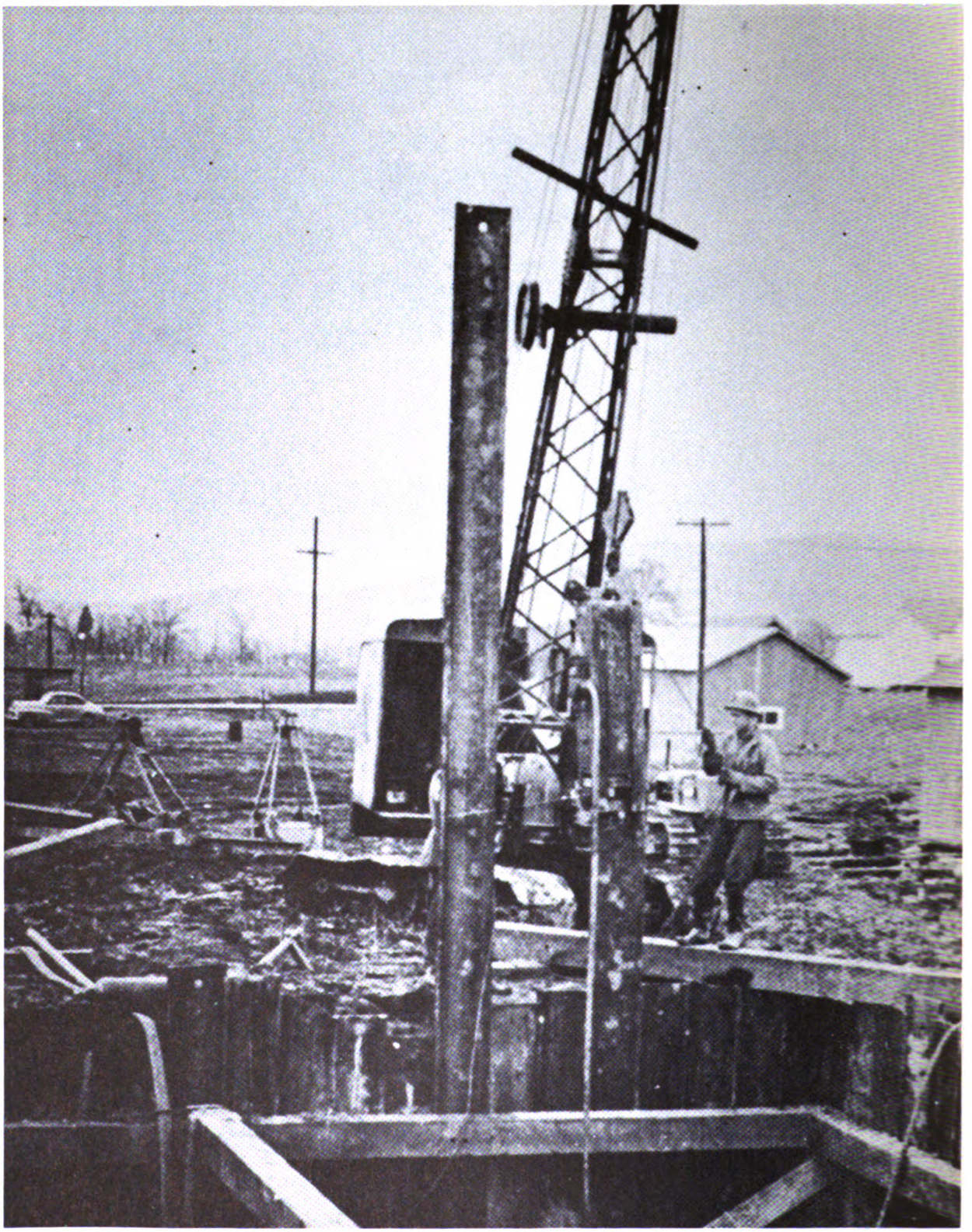

Figure 8. - Driving sheet piling for excavation of overburden.

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a loading pocket from the 1,180- to the 1,203-foot levels (see fig. 5); and a diamond-drill station on the 600-foot level. Level stations consist of crosscuts approximately 128 feet long, which are 10 feet high by 16 feet wide for 50 feet and 10 feet by 10 feet for the rest of their length (see fig. 6). Temporary reinforced-concrete bulkheads with heavy steel doors were installed 75 feet from the shaft to protect against flooding during subsequent extension of the levels (see fig. 7)

Sinking Practice

The top 60 feet of the shaft were sunk through the overburden by driving steel piling (see fig. 8) to bedrock to form a cofferdam 30 feet wide by 30 feet long. The material inside this cofferdam was then excavated by a crane with a 3/4-yard clamshell. Nine steel sets were hung, and the shaft was lined with reinforced concrete and sealed to bedrock. The concrete bearing surface on bedrock is 10 feet wide and 6 feet high. Above this, to the surface, the horizontal thickness of the concrete is 4 feet. Three concrete-lined horizontal passageways were constructed just below the surface. One of these is a manway to the permanent change house; another is for electrical and compressed-air lines; and the third is for the permanent pump lines.

After the temporary sinking headframe was erected, a Riddell shaft mucking machine, a pump discharge line, sinking pumps, air and drill-water lines, and a ventilation pipe were installed in the shaft.

Operations were carried on regularly, 3 shifts a day, 7 days a week. The working force consisted of 40 men: 1 superintendent, 1 engineer, 1 timekeeper, 3 shift bosses, 3 surface men, 3 hoisters, 3 landers, 1 electrician, 1 carpenter, 1 mechanic, 1 mechanic's helper, and 21 miners.

Pressure Grouting

Three alternative methods were carefully considered for sinking the shaft through the water-bearing formations. These were:

1. To prepump the ground surrounding the shaft with 6,000-g.p.m. deep-well pumps through boreholes of 12-inch initial diameter and reamed to 30 inches. However, it was realized that ground conditions would make it difficult to keep holes in alignment and to keep the pilot holes open pending reaming to the finished size. The possibility also existed that a hole might penetrate comparatively tight ground and thereby preclude successful drawdown of the water near the shaft. Contractors would not guarantee completion of the holes, so this plan was abandoned.

2. To freeze the ground surrounding the shaft. Persons familiar with European practice in this method did not agree as to the success that might be achieved. However, it is believed that this method would not have been practical because adverse ground conditions precluded even approximate alinement of the boreholes required for brine circulation.

3. To pressure grout the ground surrounding the shaft. Because of previous successful results obtained[4/] by pressure grouting in sinking shafts through water-bearing formations, this method was adopted as the most feasible in view of all the known circumstances.

4/ Allen, W., and Crawhall, J. S., Shaft Sinking in Dolomite at Venterspost: Jour. Chem., Met., and Min. Soc. South Africa, April 1937, pp. 502-523.

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The underlying principle of the pressure-grouting system is to seal off a block of ground from the water-bearing fractures and then to excavate within the protected block. Holes are drilled into the water-bearing formation, and a mixture of water and cement is injected under pressure to seal the water passages and, if necessary, to stabilize decomposed rock to permit safe excavation.

The grouting of the Friedensville shaft can be divided into two phases:

(1) Pretreatment of the water-bearing, fissured and partly decomposed dolomite (see table 5).

(2) Re-treatment of the dolomite (see table 6).

The arrangement of the grout mixers and pump used in this work is shown in gıis work is shown in figure 9. Continuous flow of grout was secured by using two mixing tanks. While grout was being pumped from one tank, the other was being filled with the correct amounts of cement, water, and Prepakt Aid. Prepakt Aid is a commercial preparation that retards the initial setting time of cement. Sand or fly ash was also added when large amounts of grout were required.

Pretreatment of Dolomite

The first step in sinking was to pretreat the dolomite to a depth of about 325 feet. This work was begun July 1, 1947, and completed February 3, 1948, under a subcontract.

Eighteen holes, 325 to 350 feet deep, spaced 10 feet apart and 15 feet outside the perimeter of the proposed shaft, were drilled and grouted in stages. Later seven additional holes were drilled and grouted.

The procedure for pretreating the rock follows:

1. Each hole was drilled 25 feet, or less if loss of drill water indicated an open fracture.

2. The hole was pressure washed to remove as much clay as possible.

3. Grout injection was then begun. Above 280 feet grouting was continued to a pressure of 300 p.s.i. and below 280 feet to a pressure of 400 to 500 p.s.i.

4. After the grout had set, the holes were redrilled and deepened another 25 feet, or until another fracture was penetrated. Then grouting was repeated.

Grout was mixed in the following proportions: 3 bags cement, 2 bags fly ash, and 1 to 2 pounds Prepakt Aid. The first batch of grout pumped into a hole was mixed with 45 gallons of water. Fluidity of the grout was then gradually decreased until only 25 gallons of water was used per batch.

During this operation grout appeared at the ground surface in several places within a 100 foot radius of the shaft. Later experience indicated that the grouting pressure was too great and resulted in a needlessly long travel of grout. Pretreatment proved to be unsuccessful because the shaft was flooded 3 times within the 325 feet pregrouted, and sinking was possible only by regular and elaborate test holing and grouting conducted from the shaft bottom.

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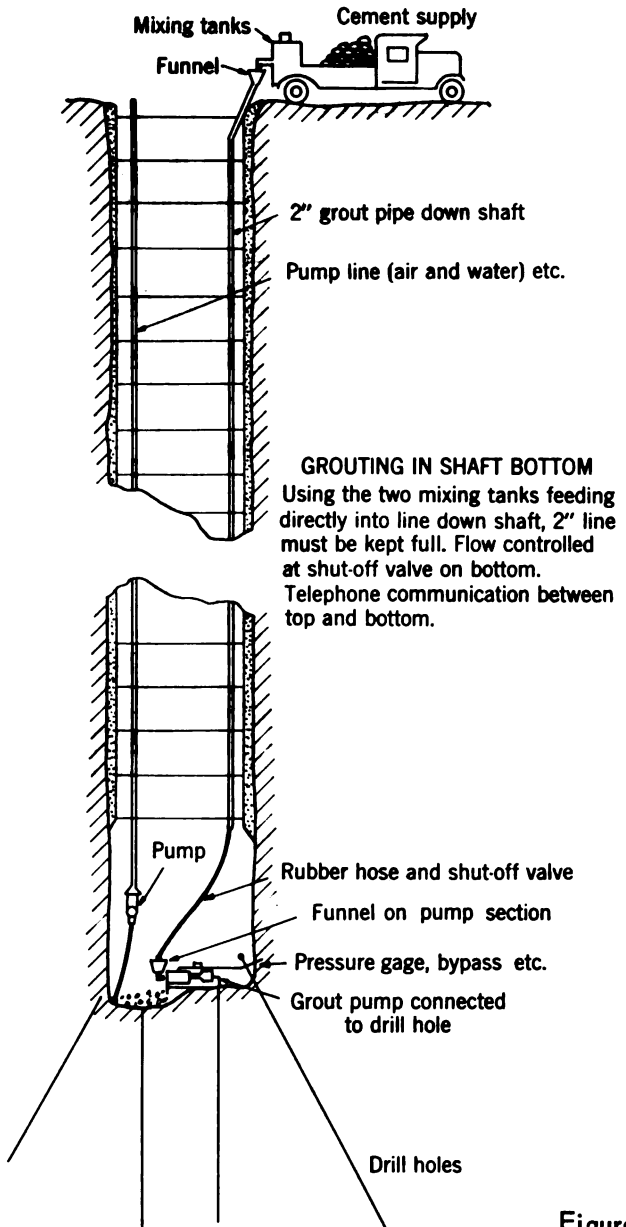
Mixing tanks
Cement supply
Funnel
2" grout pipe down shaft
Pump line (air and water) etc.
GROUTING IN SHAFT BOTTOM
Using the two mixing tanks feeding directly into line down shaft, 2" line must be kept full. Flow controlled at shut-off valve on bottom.
Telephone communication between top and bottom.
Pump
Rubber hose and shut-off valve
Funnel on pump section
Pressure gage, bypass etc.
Grout pump connected to drill hole
Drill holes

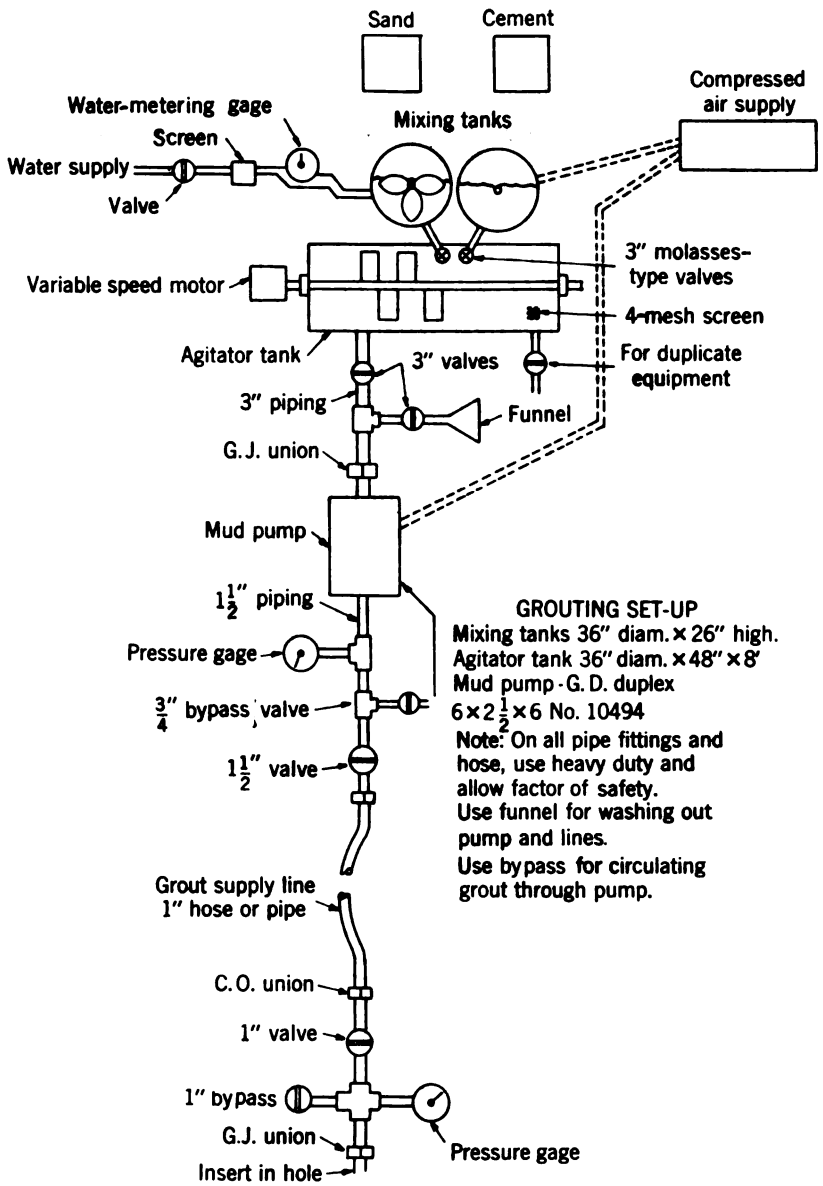

Figure 9. - Method of grouting in shaft.

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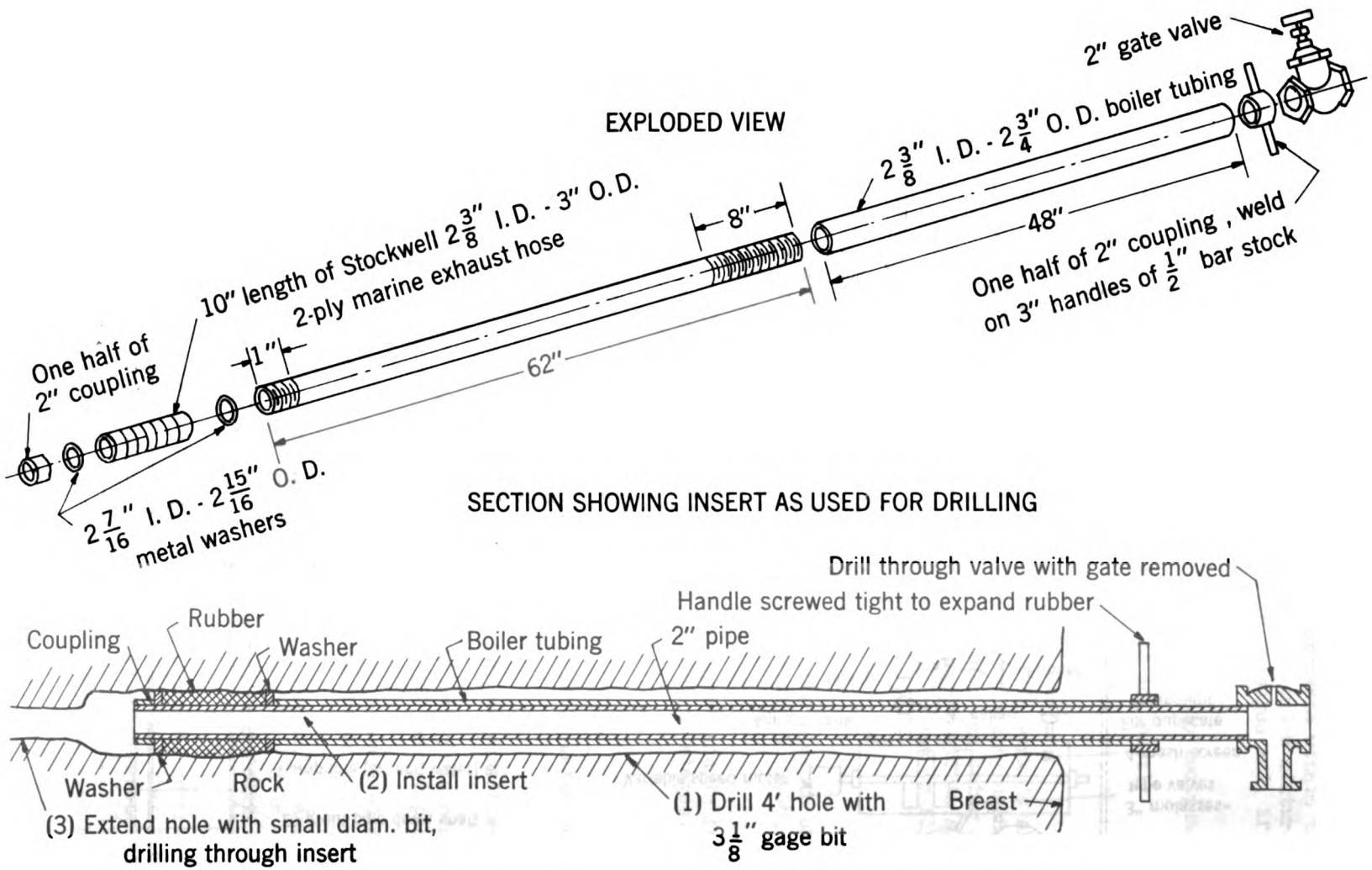
EXPLODED VIEW
2" gate valve
2 3/8" I. D. - 2 3/4" O. D. boiler tubing
10" length of Stockwell 2 3/8" I. D. - 3" O. D. 2-ply marine exhaust hose
8"
48"
One half of 2" coupling
1"
62"
One half of 2" coupling, weld on 3" handles of 1/2" bar stock
2 7/16" I. D. - 2 15/16" O. D. metal washers
SECTION SHOWING INSERT AS USED FOR DRILLING
Drill through valve with gate removed
Handle screwed tight to expand rubber
Coupling
Rubber
Washer
Boiler tubing
2" pipe
Washer
Rock
(2) Install insert
(1) Drill 4' hole with 3 1/8" gage bit
Breast
(3) Extend hole with small diam. bit, drilling through insert

Figure 10. - Insert for diamond-drill hole to control water and for grouting.

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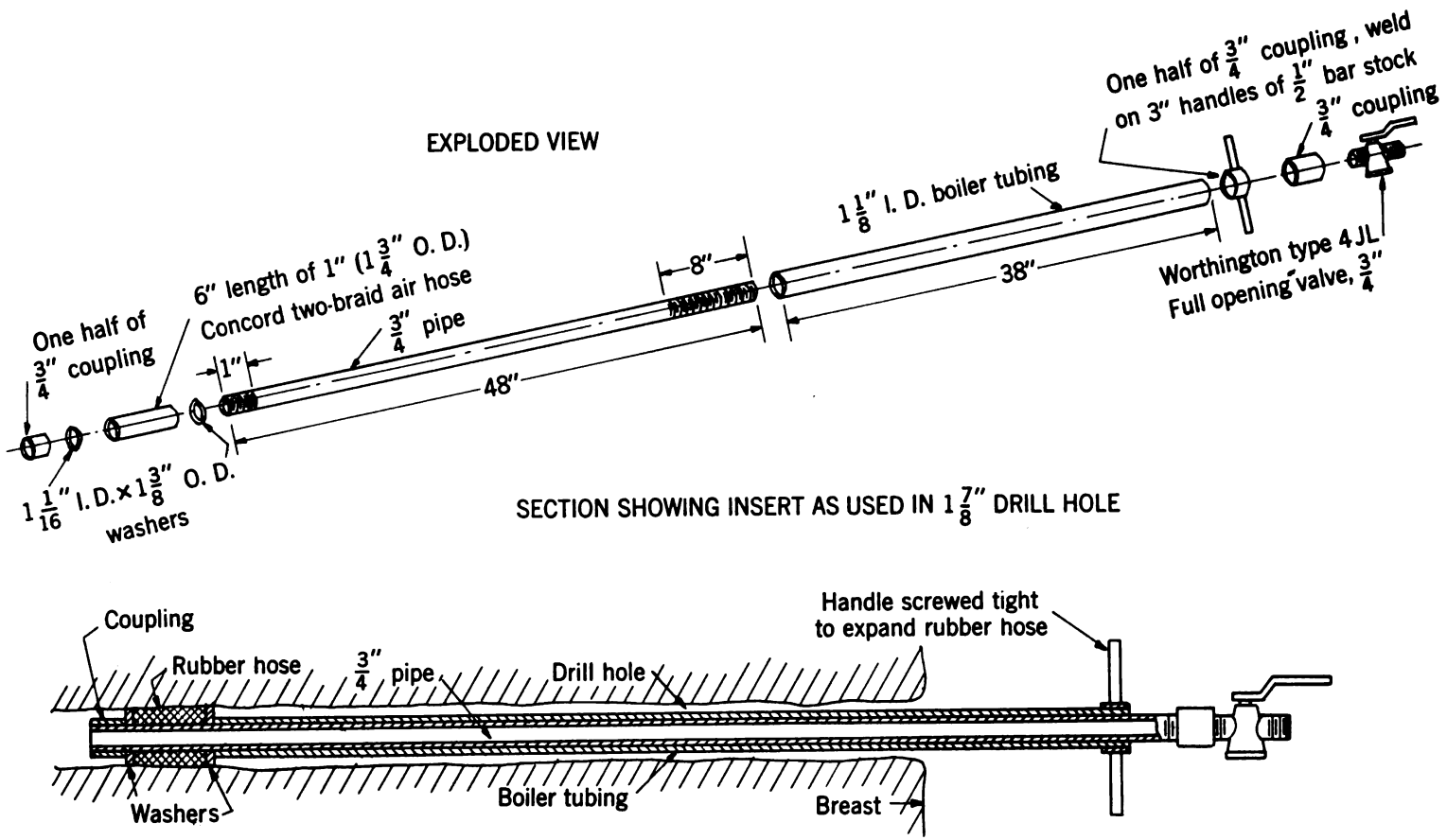
EXPLODED VIEW
One half of 3/4" coupling
6" length of 1" (1 3/4" O. D.) Concord two-braid air hose
1"
3/4" pipe
8"
48"
1 1/8" I. D. boiler tubing
38"
One half of 3/4" coupling, weld on 3" handles of 1/2" bar stock
3/4" coupling
Worthington type 4 JL Full opening valve, 3/4"
1 1/16" I.D. x 1 3/8" O. D. washers
SECTION SHOWING INSERT AS USED IN 1 7/8" DRILL HOLE
Coupling
Rubber hose
3/4" pipe
Drill hole
Handle screwed tight to expand rubber hose
Washers
Boiler tubing
Breast

Figure 10A. - Insert for percussion-drill hole.

Figure 10B. - Inserts for percussion-drill holes with high water pressure.

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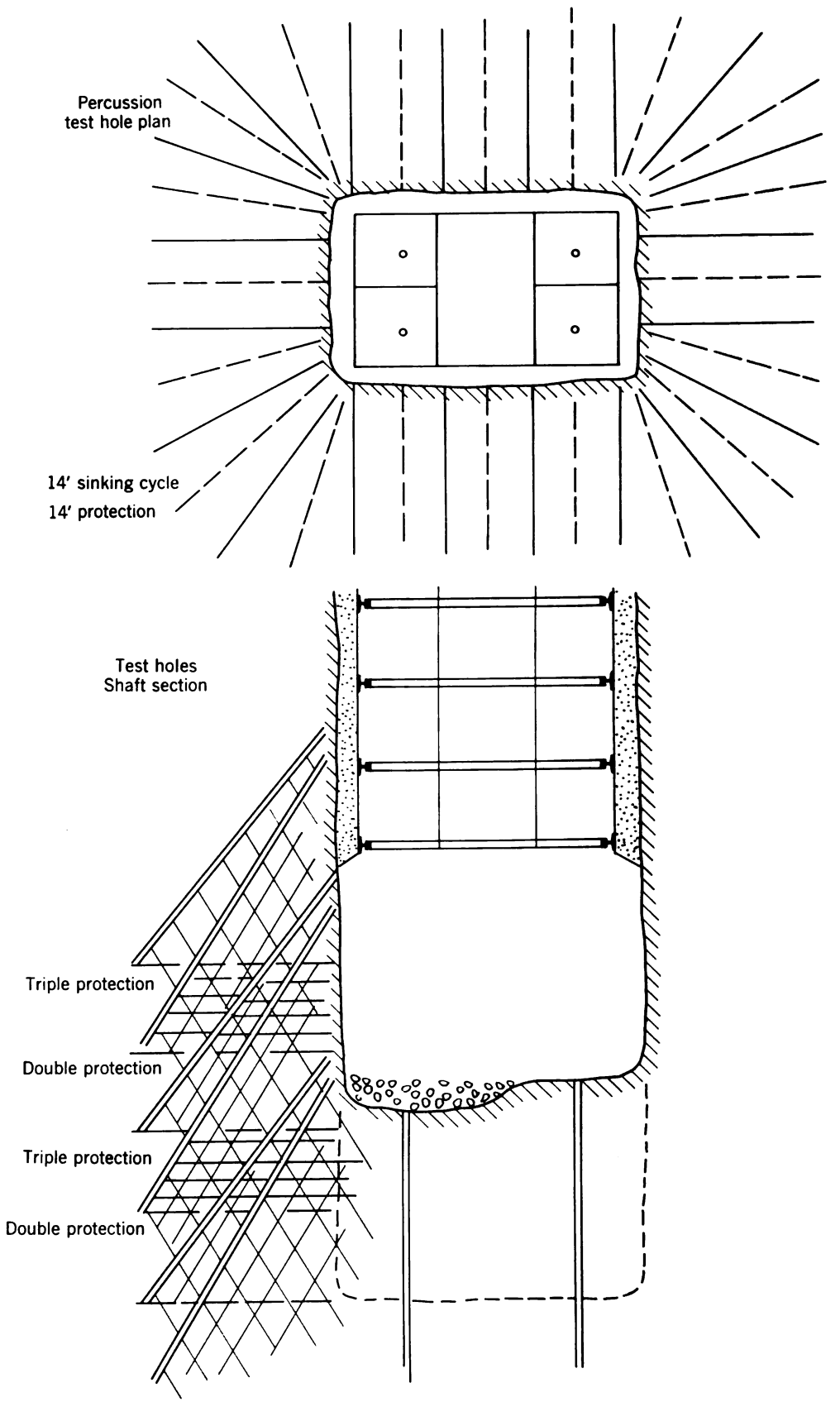

Figure 11. - Standard test-hole pattern for percussion drills.

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The presence of clay in the cavities is considered the cardinal reason for failure of this pretreatment. It was not possible to remove all clay through holes drilled from above the water table. Washing and effective grouting had to be done underground.

Re-treatment of Dolomite

Sinking had progressed to a depth of only 73 feet when a heavy flow of water broke into the shaft. After that, the dolomite was re-treated in stages by holes drilled from the shaft and horizontal workings. The procedure was as follows:

1. Test holes were drilled into the rock surrounding the sides and bottom of the shaft with both diamond and percussion drills. Percussion drills were used for holes up to 32 feet deep. Holes deeper than 32 feet were drilled with diamond drills through inserts equipped with valves and large enough to pass an EX bit (see fig. 10). Percussion test holes near the bottom of the shaft, where the water pressure was about 500 p.s.i., were also drilled through inserts. However, during most of the operation, small-diameter inserts were placed in percussion drill holes only after water was encountered.

The standard test-hole pattern (see fig. 11) using percussion drills consisted of alternate rings of 20- and 28-foot test holes with 20 holes in each ring. This pattern, however, was changed frequently to meet the requirements of varying ground conditions. When no water or clay was encountered by a ring of 20- or 28-foot holes, the shaft was sunk another 7 or 14 feet before the next ring of test holes was drilled. In addition two or more vertical test holes 16 feet long were drilled into the floor of the shaft ahead of each shaft round.

2. While the first 200 feet of shaft was being sunk, test holes that encountered clay as well as water were washed with water and compressed air at 100 p.s.i. Thorough washing was essential for successful grouting, and every effort was made to establish connections between test holes. Sometimes additional test holes had to be drilled to accomplish this.

After the static water pressure precluded washing with compressed air and water, holes that encountered clay were allowed to drain into the shaft until the water from them had cleared.

3. The pressure of the water flowing from the drill holes was measured and grouting was begun. Depending on the size and nature of the cracks or openings encountered, a thin grout containing 15 to 20 gallons of water per bag of cement or a thick grout containing 5 to 6 gallons of water per bag was used. Grout was injected until it began coming out of one or more connecting holes. The valves on the inserts in these holes were then closed, and grouting of the first hole was continued to a pressure about 20 to 50 p.s.i. greater than the water pressure. If no additional back pressure built up as grout was injected, it was assumed that the hole penetrated a large cavity. In such a case the grout was thickened by adding sand or fly ash. If this did not soon result in a pressure rise, grouting of that particular hole was temporarily discontinued while connecting holes were grouted. Then grout was injected alternately between holes until the cavity was filled. This method of rotation from hole to hole allowed the grout to build up in layers on the walls of a cavity until the cavity was sealed.

After all the holes had been grouted initially but before the grout had set completely, the grout in the inserts and in the first few feet of hole was rodded and washed out. Then the holes were regrouted to pump pressures increasing with advancing depth, until pressures of 1,000 p.s.i. were employed in the lower reaches of the shaft.

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The purpose of grouting in two stages was to conserve grout by preventing it from being pushed too far from the shaft and also to insure complete filling of even the smallest cracks in the rock immediately surrounding the shaft. The first stage of grout injected at low pressure bridged cavities or fractures relatively close to the shaft. When partly set, these plugs prevented the grout injected at high pressure from traveling beyond them. Occasionally, as indicated by a sudden drop in pressure, a plug failed before the desired maximum pressure was reached. Then the grouting of that hole was discontinued until another plug had time to set.

4. After the grout had set, holes were retested by redrilling and deepening diamond-drill holes or by drilling new percussion holes alongside grounted ones. The cycles of drilling and grouting were repeated until all the holes had been tested to their complete depth.

Because of the nature of the rock, even the most careful grouting and most elaborate drill pattern could not always insure complete sealing of all fractures. In some instances open vugs not intersected by any of the test holes were found only a few inches from a grouted hole (see fig. 12).

Concrete Pads

Where the rock in the bottom of the shaft was very badly fractured and decomposed, a concrete pad was placed on the shaft bottom (see fig. 13) to act as a bulkhead for retaining grout within the rock. Three pads were constructed, the last when the shaft was 273 feet deep.

To construct a pad, a 12- by 36- by 28-inch steel box with perforated sides and open bottom was first placed on the floor of the shaft. Two 3-inch pipes were welded into holes cut in the top of the box. One of these pipes was later employed as an inspection pipe. The other was used for pumping and was equipped with a foot valve and screen. With the aid of a templet, casing pipes for the test holes that were to be drilled through the pad were correctly located and alined. Canvas curtains were hung to deflect dripping water onto an H-beam wall plate, which served as a water-collecting ring. Four grout pipes and a pipe to carry water from the collecting ring to the shaft bottom were installed. About 3 feet of 3-inch crushed limestone was then placed on the bottom of the shaft, and a tight tongue-and-groove plank floor was laid over the stone and caulked around the edges. Finally, about 50 cubic yards of concrete was placed on top of the floor to form a pad 3 feet thick.

During the initial setting time of the green concrete, all water seeping into the bottom of the shaft, including the water from the collecting ring, was pumped from the crushed stone below the pad. After that, water was allowed to come up through the pipes in the pad, and pumping was continued from above the pad for 3 days until the concrete had set. Grout was then injected into the crushed stone at a pressure of 50 p.s.i. After this had set, test holes were drilled, and grouting proceeded. The pad was later broken with paving breakers, and shaft sinking was resumed.

Underwater Plugs in Shaft

In spite of all precautions, on four occasions large flows of water broke into the shaft and flooded it to the water level of the surrounding ground.

In 1 instance, when the shaft was 247 feet deep, the bottom of the shaft appeared firm enough not to require a pad and test drilling was begun. However, one hole encountered water that enlarged the hole so quickly that it would not retain an insert.

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Figure 12. - An open vug near a grouted hole. (1) Diamond-drill hole full of grout; (2) open vug - 10 g.p.m.; (3) ball of clay with grout (white spots).

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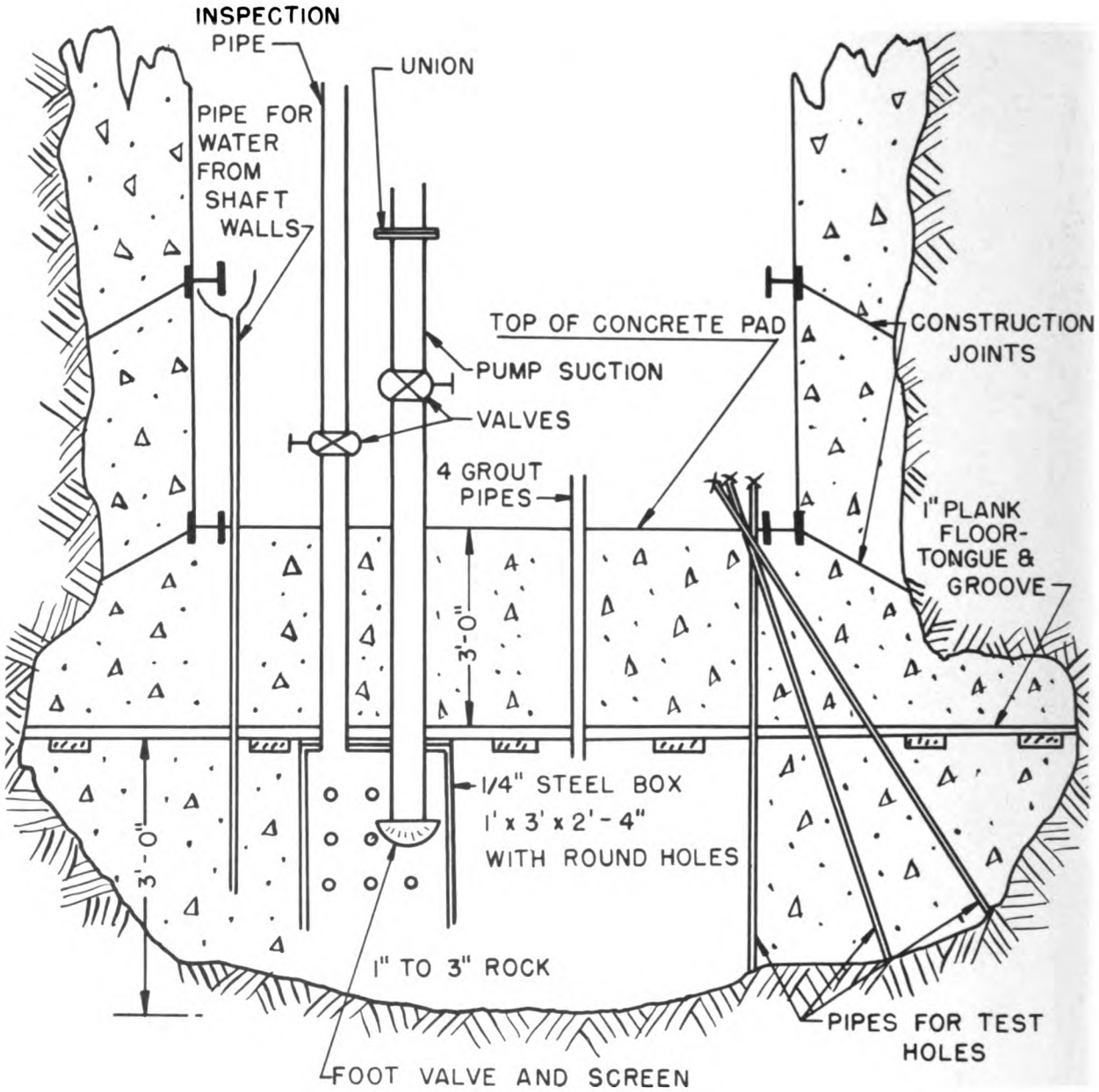

Figure 13. - Construction details of a concrete pad.

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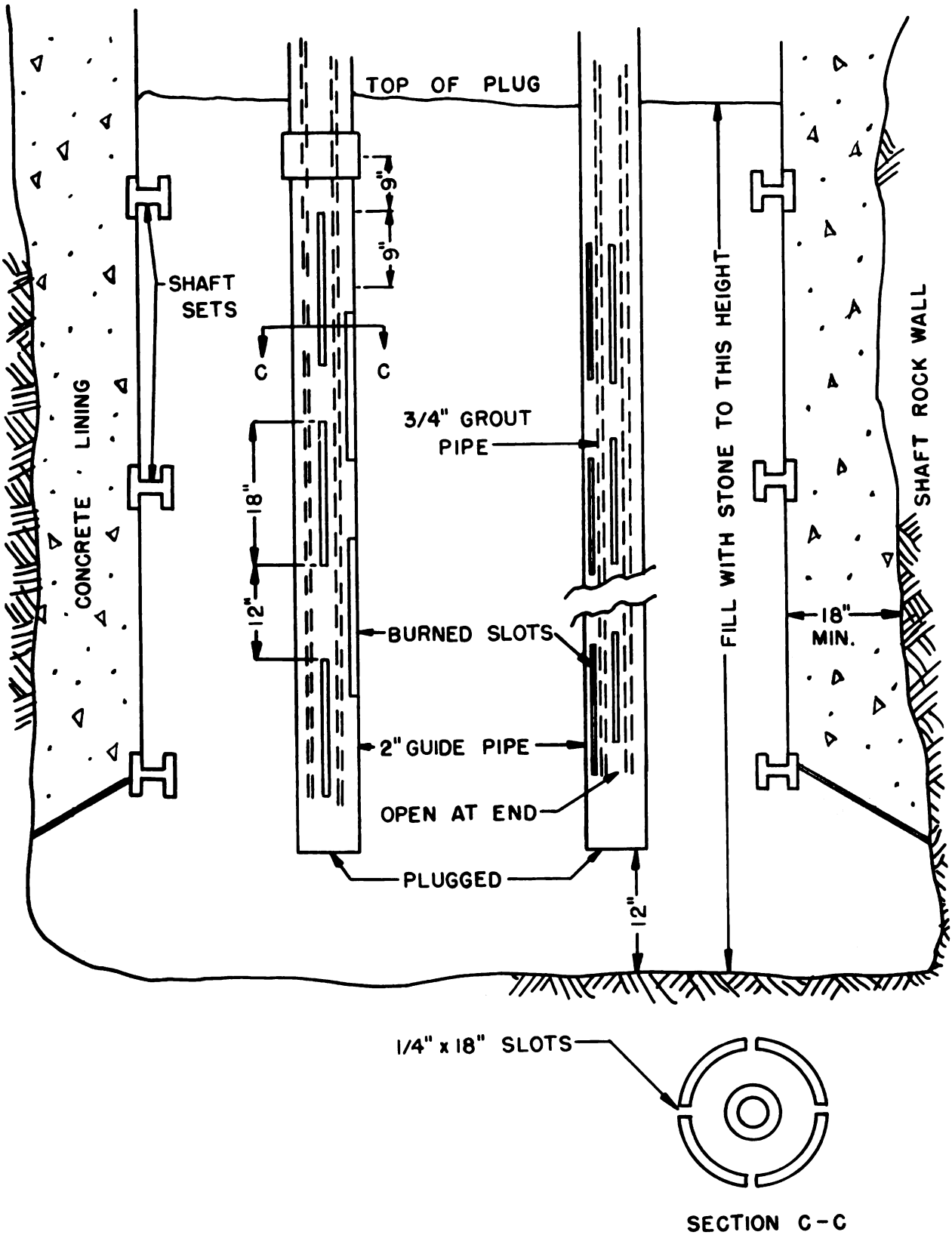

Figure 14. - Method of construction of the underwater plug in a shaft.

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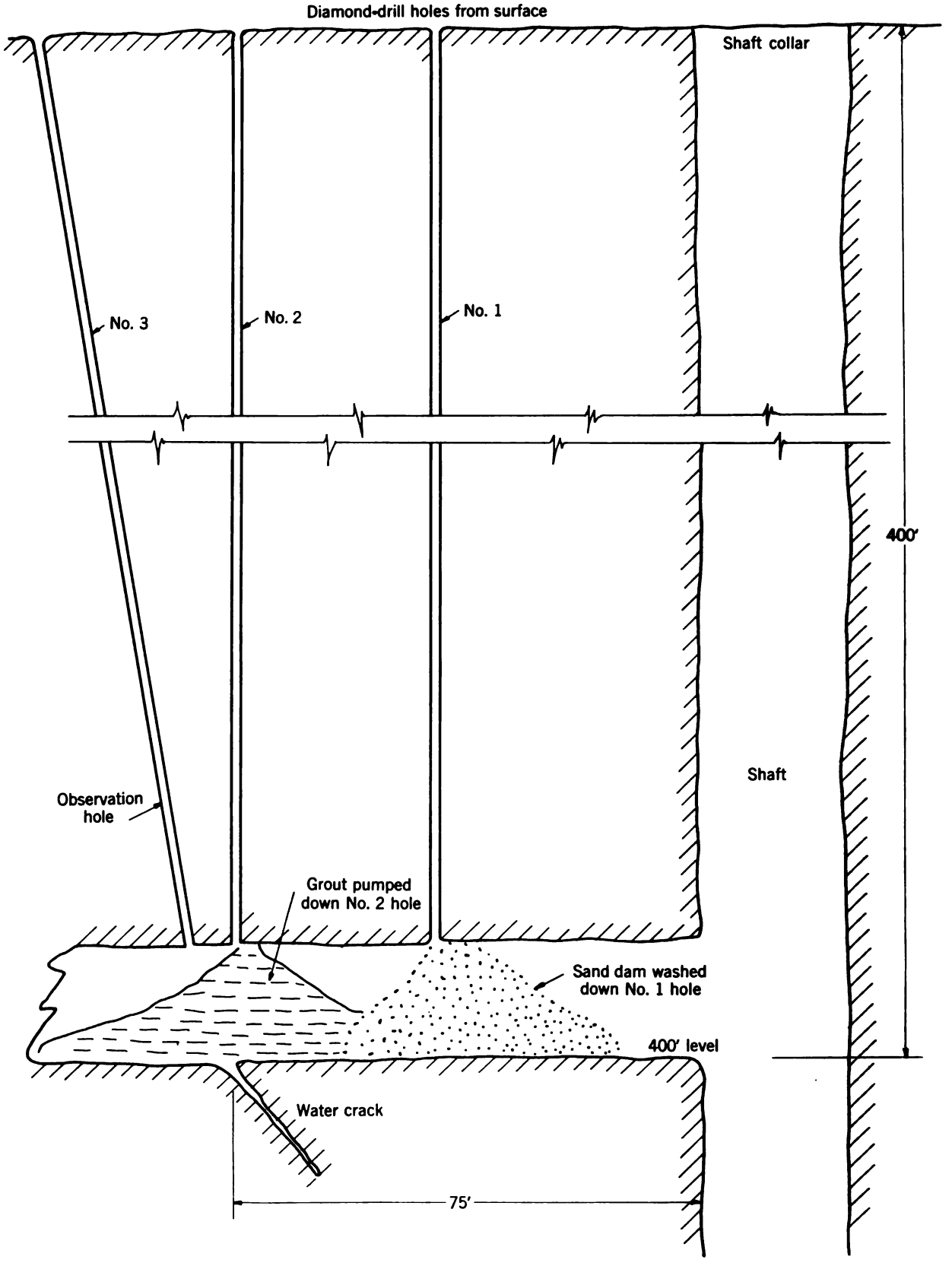

Figure 15. - Method of constructing underwater plug on 400-foot level.

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The diameter of the hole and the flow of water increased rapidly, and within a short time the shaft was flooded.

On January 6, 1949, when the shaft was 146 feet deep, another such break occurred. A shaft round had been blasted, and mucking was begun at 5 A.M. The sinking pump was discharging 100 gallons of water a minute. At 5:15 A.M. the shift boss noted that muddy water was entering the bottom of the shaft through a fracture. The center of this fracture was filled with grout but clay on the sides of the fracture had prevented the grout from bonding. The flow increased so rapidly that the miners could not remove the mucking machine or pump. Within 30 minutes the water rose 127 feet in the shaft - equivalent to an average flow of 8,000 gallons a minute.

Pumping from the surface was begun with 3 pumps having a total capacity of 825 gallons a minute, but after dropping only 13 inches the water level remained stationary. Five pumps with a combined capacity of 5,800 gallons a minute were then placed in operation, but the water was lowered only 42 feet.

It was evident that an underwater plug would have to be placed. First the mucking machine and sinking pump were recovered by a deep-sea diver and his assistant. Then mud on the shaft bottom was removed by churning the mud with long blow pipes and pumping the muddy water with a compressed-air pump that had been lowered to the shaft bottom.

Pumping from the top of the shaft was then discontinued, and a typical underwater plug was poured (see fig. 14). Ten guide pipes, 2 inches in diameter and slotted 10 feet at their ends, were lowered almost to the bottom of the shaft. Nine 3/4-inch grout pipes were then lowered inside 9 of the guide pipes.

Crushed limestone, 3/4 to 3 inches in size, was poured through a 20-inch ventilation pipe and through the pipe used for concreting until the crushed stone reached the top of the proposed plug 14 feet thick. Measurements were taken at several places to check the thickness and distribution of the stone. The top surface of the crushed rock was virtually level and not appreciably cone-shaped as might be expected.

Grout was pumped by 3 triplex pumps into the crushed stone through 9 grout pipes simultaneously, until all the voids in the crushed rock were filled. Each batch of grout used for this purpose contained 3 bags of cement, an equal amount of sand, 1 bag of fly ash, 1 pound of Prepakt Aid, and 35 gallons of water. The grout was allowed to set for 3 days; then the water was pumped out of the shaft, the steel sets were cleaned, and drilling and grouting of test holes through the plug were begun.

Several controls were considered important in successfully casting underwater plugs:

1. It was necessary to place the guide pipes accurately. They were lowered within 1 foot of the shaft bottom before the plug was cast. The inner 3/4-inch grout pipes were at first lowered within 2 feet of the bottoms of the outer pipes and later raised as the grout rose. Pumping of the grout through 9 pipes at a time was distributed among all 10 guide pipes. The level of the grout was measured by a plumb bob lowered on a steel tape through the extra 2-inch guide pipe.

2. Grout lines were kept tight to prevent air leakage. Suction was thus maintained, and grout could not drop freely through the line. If grout had dropped freely it would have had such a high velocity when it reached the bottom that it would have dispersed.

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3. Pumping was at a moderate and even rate to avoid surges with the result that the grout built up in flat cones that effectively filled the voids in the crushed stone.

4. The volume of grout required to fill voids in the gravel was calculated.

5. The water level in the shaft was recorded continuously while grout was being placed.

It is noteworthy that, in the above case the water level in the shaft dropped soon after grouting was begun; the volume of grout pumped exceeded the calculated volume by about 1,500 cubic feet; and not until this amount of grout had been pumped was there a rise of the water level or a rise of grout through the gravel. Identical phenomena were observed when the other underwater plugs were cast. It is believed that the grout, being heavier than water, flowed down into the existing fracture at sufficient velocity to create a plunger effect, drawing water along with it. When the fracture was filled or bridged and no more grout was flowing into it, the water in the shaft was displaced by additional grout and began to rise again.

Underwater Plug in a Level

After the initial drift on the 400-foot level had been driven 128 feet from the shaft, a hitch for a concrete bulkhead was begun about 75 feet from the shaft. The hitch had been cut in the back and on the sides of the drift and a round into the floor had been drilled and blasted, when a sudden burst of water entered the workings from a large, mud-filled fracture opened by the blast. This mishap occurred although the level had been test drilled and grouted while it was being driven and again test holed at the site of the widening. Within 3 hours the shaft was flooded to 23 feet of the surface. The average rate of flow into the shaft was later calculated to be 20,000 gallons a minute.

A plan to construct an underwater plug was first tested on a plexiglass model. The plan in essence consisted of forming a sand dam in the station between the fracture and the shaft and then casting a grout plug into and over the fracture, both the sand and grout being introduced through diamond-drill holes bored from the surface to intersect the 400-foot level (see fig. 15). For the model studies, fly ash was substituted for grout, and the underwater angles of repose of different grout mixes were measured separately in troughs. The plan was based on two important assumptions:

1. That the fracture through which the water had entered the 400-foot level had been scoured free of clay and decomposed rock.

2. That the minor leaks in the remainder of the shaft were insignificant and that pumping from the shaft collar would create a flow of water into the crosscut from the fracture; or, conversely, that placing any fluid or solid in the shaft or crosscut would create a flow out of the crosscut into the fracture and that this flow would be maintained until the fracture was blocked.

Diamond drilling from the surface was then begun. Wedging the holes to minimize deviation was attempted but was unsuccessful because of the nature of the ground. Thus it was necessary to drill 6 holes before 3 pierced the 400-foot level at desired points. One of these intersected the level midway between the fracture and the shaft; the other two at the top of the bulkhead hitch above the fracture in the floor.

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Although the holes had been surveyed as accurately as possible, it was important to know their exact distance from the sides of the drift or level station. For making these measurements, an AX casing was slotted and notched at the bottom. A 1/2-inch rod 6 feet long was hinged to the casing with a shear pin in such a manner that, when lowered into the drift on a string of matched casing, the rod dropped at right angles to the casing and was held in that position by the short end of the rod, which rested in the notch at the bottom of the casing. The casing was then rotated at the surface until the rod touched one side of the drift and then the other. The angle to which the casing had been turned was measured, and the exact distance of the drill hole from one side of the level was calculated. When the casing was pulled, the pin holding the 1/2-inch rod was sheared, and the rod dropped to the floor of the level. It was found that the hole to be used for the sand barrier was 4 feet from one side of the shaft station and thus about 12 feet from the other side.

Grout mixed in the proportion of 1 bag of cement to 5-1/2 gallons of water was then pumped down a pipe through the drillhole nearest the fracture. Soon after grouting was begun, the water level in the shaft dropped 16 inches. Later the water level rose slowly again at a rate equal to the volume of grout that was being pumped. This same phenomenon had been observed when the other underwater plugs had been cast in the shaft. After 1,300 cubic feet of grout had been placed, a bailer used in the observation hole indicated that the grout had risen to floor level.

Forming of the sand dam was then begun. First, sand was washed directly down the drill hole until a flat cone was formed on the level directly under the hole. Then a length of AX casing, plugged at the bottom with a slot or window cut in one side of it, was lowered down the hole. The window was turned to point across the level to its far side, and additional sand was washed down the pipe. After the sand dam was a few feet high all the way across the level, additional grout was pumped over the fracture. This grout was mixed in the proportions: 1 bag of sand, 1 bag of cement, 5/8 pound Prepakt Aid, and 6 gallons of water. The level of the grout was measured intermittently by a bailer in the observation hole.

During grouting, water was pumped continuously from an inverted 30-inch cone of sheet metal attached to a pipe in the shaft placed just below the 400-foot level. Whenever grout was observed in the shaft water grouting was discontinued, and more sand was added to the dam. Sand and grout were placed alternately until the grout plug filled the level to its back.

After grouting, the two holes in the crosscut above the grout cone were drilled through the cone, and grout was added at low pressure to fill any possible shrinkage. After this grout had set, the same holes were redrilled and deepened 20 feet below the floor of the crosscut. Packers were placed in the grout cone, and the bottoms of the holes were grouted under moderate pressure. After this grout had set for 5-1/2 days, water was pumped from the shaft without incident. Sixteen horizontal holes were drilled from the shaft 8 to 15 feet under the 400-foot level into the area below the breakout. These were also grouted. During removal of the sand dam and the grout plug (see fig. 16), other test holes were drilled and grouted from the level. A concrete bulkhead, with its steel door, then was placed over the area through which water had entered the shaft (see fig. 7). Finally, it was necessary to clean up several hundred tons of clay, sand, and gravel which had been washed into the shaft by the rush of water.

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Drilling

Test holes were drilled both with diamond and percussion drills. EX size coring or plug bits were generally used for diamond drilling.

Percussion drilling was done with 55-pound sinkers, using 1-inch, hexagonal drill rods and detachable insert bits. Drill rods in 4-foot changes with maximum lengths of 32 feet were used. The long rods were handled from the sinking bucket. Detachable, tungsten carbide insert bits ranged from 1-7/8 to 1-5/8 inches in diameter, in 1/32-inch increments for the several steel changes. The life of the bits averaged 249 feet. Bits cost 5.7 cents and steel 7.25 cents per foot of hole drilled.

Blast rounds were drilled with the same percussion drills used for long-hole drilling. A normal sump-type round of 42 holes was used to break half the shaft bottom at a time. Thus one side of the shaft bottom was always lower than the other to serve as a sump for pumping. Holes were drilled to a maximum depth of 8 feet, and the round generally broke 7 feet deep. Seven miners using 5 machines completed a round in 4 hours.

Blasting

Shaft rounds were blasted with 1-1/4- by 8-inch sticks of Hercules 40-percent gelatin, using standard electric delay detonators. Circuits were wired in parallel and fired from a switch at the shaft collar by the shift boss.

An average of 4.95 pounds of dynamite per cubic yard was used in breaking shaft rounds and an average of 6.56 pounds per cubic yard in breaking level station rounds.

Blasting fumes were exhausted through a 20-inch ventilation tube by a Coppus Ventair blower driven by a 15-hp. motor. About 45 minutes was required to clear the smoke. During the rest of the working cycle, fresh air was blown into the shaft by reversing the flow through the ventilation tube.

Mucking

Broken rock on the shaft bottom was loaded into the 50-cubic foot sinking bucket by a Riddell shaft mucker with a 3/8-yard clamshell. A minimum of 4 men was required for mucking, 2 to operate the mucking machine, 1 hoistman, and 1 truck driver. However, the full crew was generally used. An average shaft round of 60 buckets was mucked in 9 to 10 hours.

Pumping

Two 40-hp. electric pumps, each with a capacity of 225 gallons a minute under a 400-foot head, were normally available for pumping water that collected in the shaft bottom. Before blasting, these pumps were hoisted out of the way by tugger hoists attached to steel sets higher up in the shaft.

At first water was pumped directly to the surface. As the shaft was deepened, 1,000-gallon-per-minute pumps were installed at the 418-, 818-, and 1,068-foot pumping stations, and the sinking pumps delivered water to reservoirs at these stations. Additional, temporary pumping substations using 40-hp. pumps were installed at intermediate levels to reduce the head on the sinking pumps.

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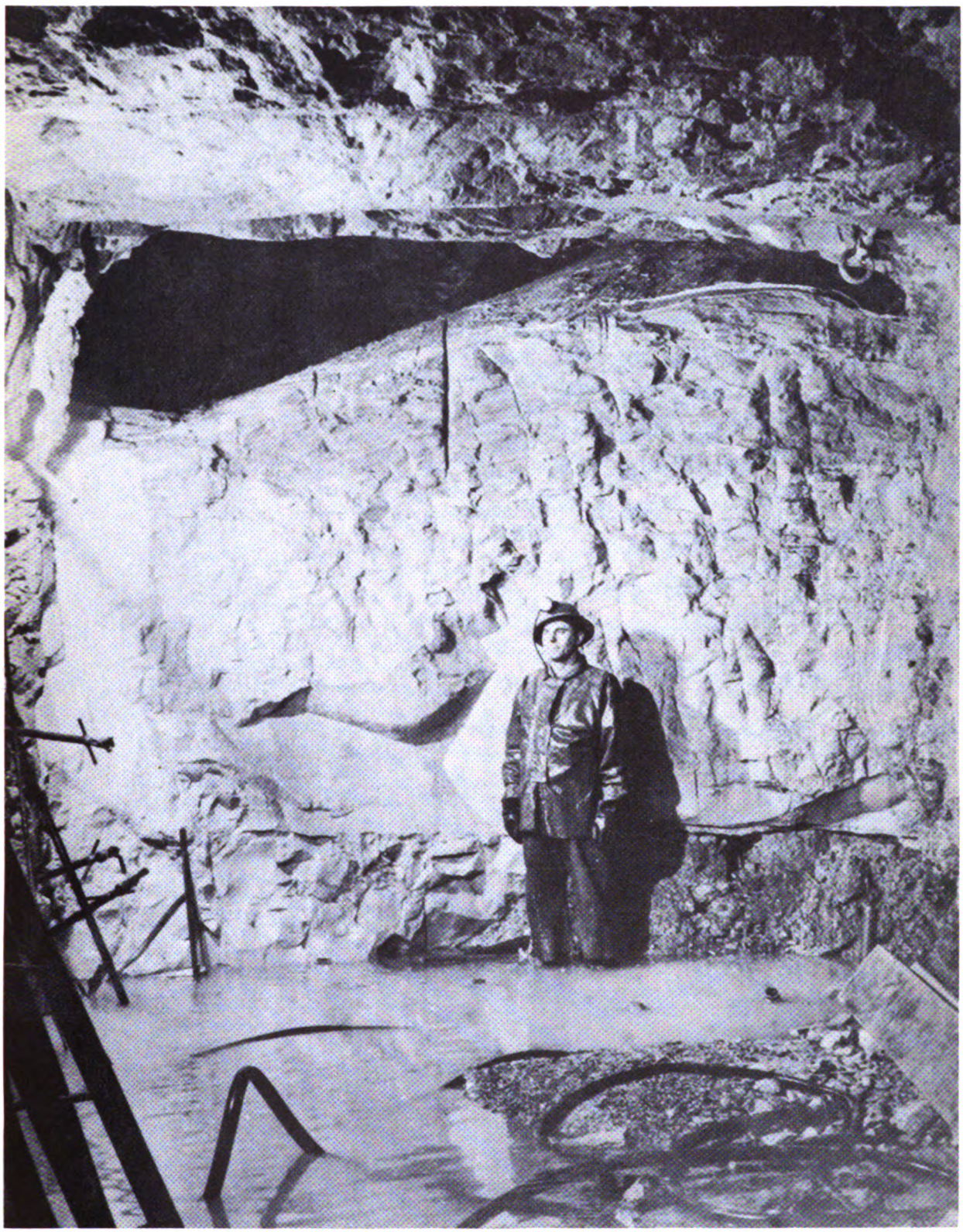

Figure 16. - The grout plug on the 400-foot level.

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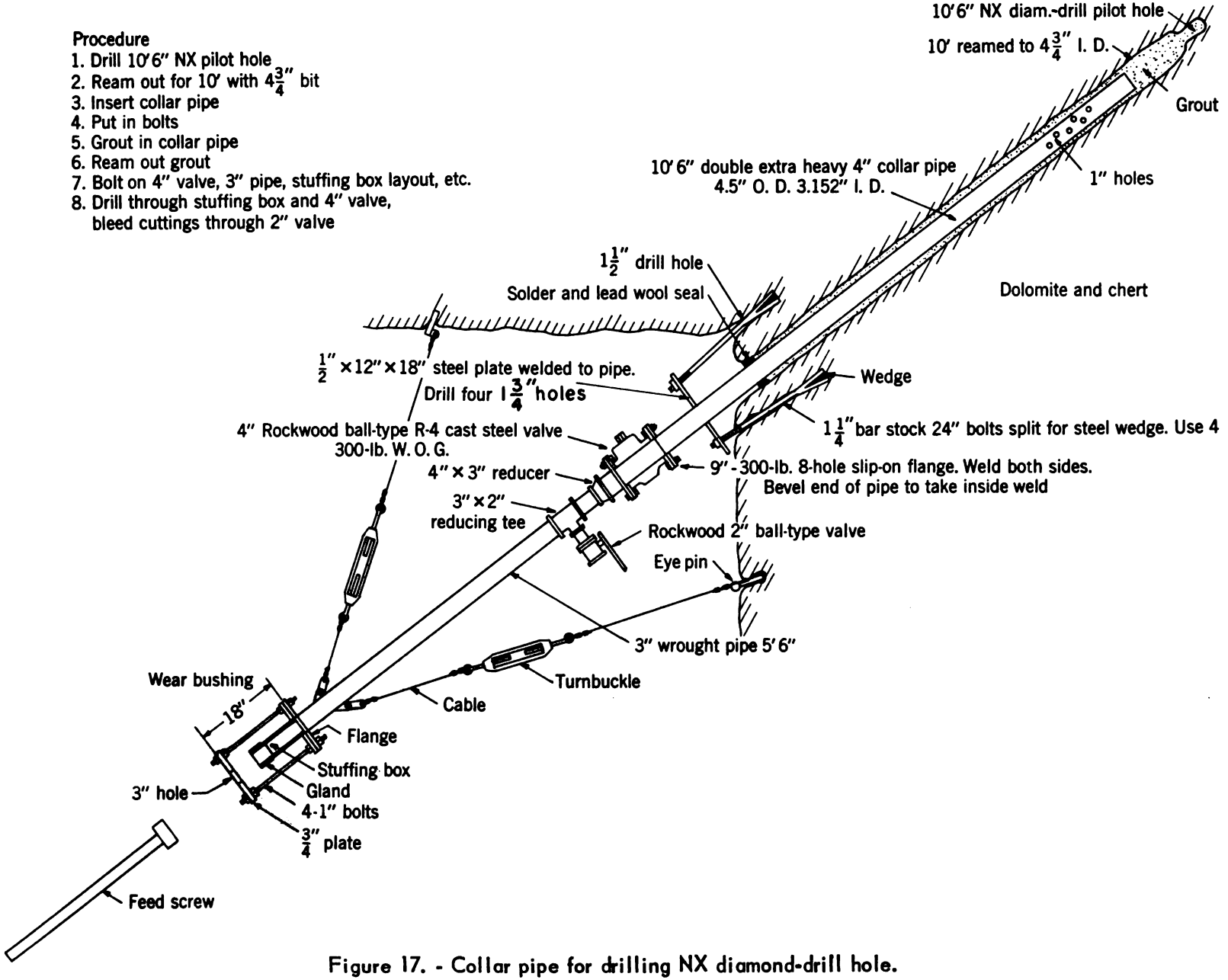
Procedure
1. Drill 10'6" NX pilot hole
2. Ream out for 10' with 4 3/4" bit
3. Insert collar pipe
4. Put in bolts
5. Grout in collar pipe
6. Ream out grout
7. Bolt on 4" valve, 3" pipe, stuffing box layout, etc.
8. Drill through stuffing box and 4" valve, bleed cuttings through 2" valve
10'6" NX diam.-drill pilot hole
10' reamed to 4 3/4" I. D.
Grout
1" holes
10'6" double extra heavy 4" collar pipe
4.5" O. D. 3.152" I. D.
1 1/2" drill hole
Solder and lead wool seal
Dolomite and chert
1/2" x 12" x 18" steel plate welded to pipe.
Drill four 1 3/4" holes
Wedge
1 1/4" bar stock 24" bolts split for steel wedge. Use 4
4" Rockwood ball-type R-4 cast steel valve
300-lb. W. O. G.
9" - 300-lb. 8-hole slip-on flange. Weld both sides.
Bevel end of pipe to take inside weld
4" x 3" reducer
3" x 2"
reducing tee
Rockwood 2" ball-type valve
Eye pin
3" wrought pipe 5'6"
Turnbuckle
Cable
Wear bushing
18"
Flange
Stuffing box
Gland
3" hole
4-1" bolts
3/4" plate
Feed screw

Figure 17. - Collar pipe for drilling NX diamond-drill hole.

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Figure 18. - Water being discharged at 250 p.s.i. from NX diamond-drill hole on 600-foot level.

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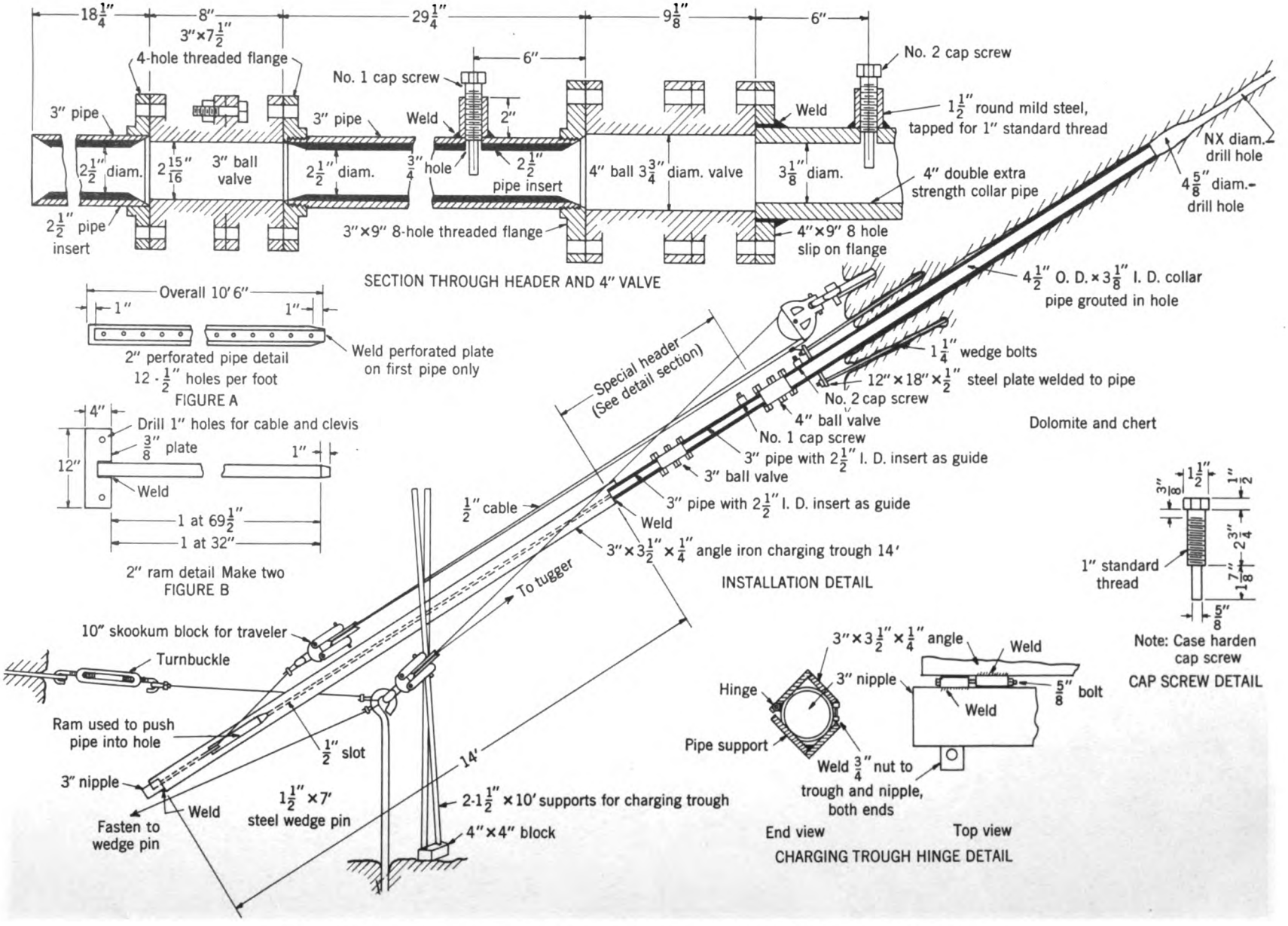

Figure 19. - Method of installing perforated pipe in NX diamond-drill hole.

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Before beginning to lower the water table near the shaft and ore body, 39 NX diamond-drill holes 35 to 380 feet deep were drilled into the country rock from a diamond-drill station on the 600-foot level. Each hole was drilled through a 4-inch pipe and ball valve (see fig. 17) until heavy water was encountered. In the majority of instances, pieces of rock and considerable amounts of mud and abrasive sand were discharged with the water under a pressure of about 250 p.s.i. (see fig. 18). To minimize the chance of rocks or abrasive sand leaving the holes and subsequently damaging pumps, the holes were lined with 2-inch perforated pipe in 10-foot sections. Each section was perforated with 100 holes, 1/2 inch in diameter, and beveled at each end to form slip joints. The clarity of the water that was later pumped from these holes has proved the value of the perforated linings.

Before a hole was lined with 2-inch perforated pipe, a special header and a charging trough were attached to the 4-inch ball valve on the collar pipe of the hole (see fig. 19). A 10.5-foot section of perforated pipe was then placed in the charging trough; the ball valve on the collar pipe and on the header were opened; and the perforated pipe was pushed into the hole by a ram traveling in the charging trough and pulled by a 1/2-inch cable attached to a tugger hoist. Cap screw 1 (see fig. 19) in the header was used to hold the section of perforated pipe in place until the next section was ready to be pushed into place. Cap screw 2 in the collar pipe was used to hold the final section of perforated pipe in place after the hole had been completely lined.

After the holes were lined, all holes were connected with 3-inch pipe to a single manifold or header (see fig. 20). As a safeguard, a bypass T-connection with valve was placed in each 3-inch line. These bypasses will allow holes that may become plugged with mud and sand to be cleared by water injected under a high back pressure. The manifold was then connected to four 450-hp. pumps, each having a capacity of 3,000 g.p.m. under a 500-foot head and discharging to the surface through 4 temporary 12-inch lines. Pumping at this station was not begun until the shaft had been sunk.

The permanent pumping installation will include two 20-inch pump lines; two 390,000 gallon sumps at each of the 418, 818-, and 1,068-foot pump stations (see fig. 6); five 3,000 g.p.m. pumps at both the 418-, and 818-foot stations; two 1,700 g.p.m. pumps at the 1,068-foot station; and two 350 g.p.m. deep well pumps suspended from the 1,068-foot station to pump out the sump at the shaft bottom. Each battery of pumps will deliver water to the sump above.

Concreting and Shaft Support

Concrete was placed as soon as required for support. At 2 places it was considered advisable to cast less than 1 set. Generally two to three 7-foot sets were concreted at 1 time, but, where ground permitted, 6 sets were cast.

It took the crew about 48 hours (6 shifts) to prepare for concreting a 42-foot vertical section of shaft. The concrete lining was ordinarily placed 18 inches to 2 feet from the shaft bottom.

First, the steel sets were hung on 7-foot centers by assembling them, one at a time, on the shaft bottom, hoisting them, and bolting them in place. The sets were then alined, plumbed, and blocked.

One bearing set was placed at each level. It was anchored 3 feet into the shaft walls with hitches cut in the rock.

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Reinforcing steel, consisting of 7/8-inch-diameter rods tied together to form 18-inch squares, was placed 3 inches outside the sets. In extremely fractured ground, rods were spaced to form 6-inch squares, and additional reinforcing was placed 15 inches from the steel sets (see fig. 21).

Leaks in the rock walls that could be pinpointed were drilled and piped directly to the inside of the shaft. Other leaks, where water seeped out through an area or long fracture, were boxed, and pipes were placed to drain the water from the box to the inside of the shaft. This was done to prevent cement washing from the fresh concrete. Originally, grout was injected through these pipes to seal the leaks after the concreting was completed. However, grouting through these pipes was discontinued after the shaft was 500 feet deep because it was felt that open weep holes would prevent high water pressure from developing behind the concrete lining.

A bracket or bearer to support the two permanent 20-inch pumplines was also installed before concreting. It was placed in hitches cut into the rock and concreted later. These bearers were placed at 42-foot invervals down the shaft and not connected to the steel sets.

Wooden concrete forms were placed next. The flooring was attached to the bottom set and was inclined downward at 30° toward the shaft walls. Fourteen placement boxes were located on top of the flooring (see fig. 22). The open ducts formed by these boxes and the slope of the flooring later permitted a tight joint to be cast at the top of the next section of concrete.

Forms for the sides of the concrete lining were made of 2-inch planks placed vertically between the outside H-beams of the sets. To hold them in place, the planks were blocked and wedged against the inner sides of the outer flanges. The steel sets were thus set into the concrete by the thickness of an H-beam flange. Side forms were installed, 1 vertical 7-foot section at a time, as the concrete was placed.

"Ready-Mix" concrete was delivered to the shaft collar by two mixer trucks from a nearby batching plant. Concrete was mixed in the proportions 1:2.5:3.5. Aggregate consisted of limestone crushed to 1/2 to 3/4 inches. To each bag of cement, 0.4 pound of pozzolith (dispersing agent) were added to waterproof the concrete and make it easier to place. The amount of water to be added was determined by slump tests because sand and aggregate were stored outside, and their moisture varied according to the weather. Enough water was added to result in a 4-inch slump. Accurate and complete records were kept of the slump tests and also of compression tests on samples taken at the shaft collar and from the forms. The desired minimum compression strength was 3,000 pounds per square inch after 28 days. All casts exceeded this.

At the shaft collar the mixer truck discharged the concrete into a 6-inch steel pipe, which extended down the shaft to a header resting on a solid timber support just above the section to be concreted (see fig. 23). An "elephant-trunk" spout made of pipes with flexible joints was attached to the header, and the concrete was placed in the forms (see fig. 24). During concreting telephone communication was maintained between the shaft bottom and the surface.

The practicality of dropping concrete vertically down a pipe several hundred feet deep was questioned at the outset. It was believed that the concrete would segregate and the header would erode rapidly. This was not the case. The concrete was discharged from the header slowly enough to be caught by hand, and accurate tests showed that there was no segregation. Furthermore, the dead end at the bottom of the header was free of concrete when the operation was completed.

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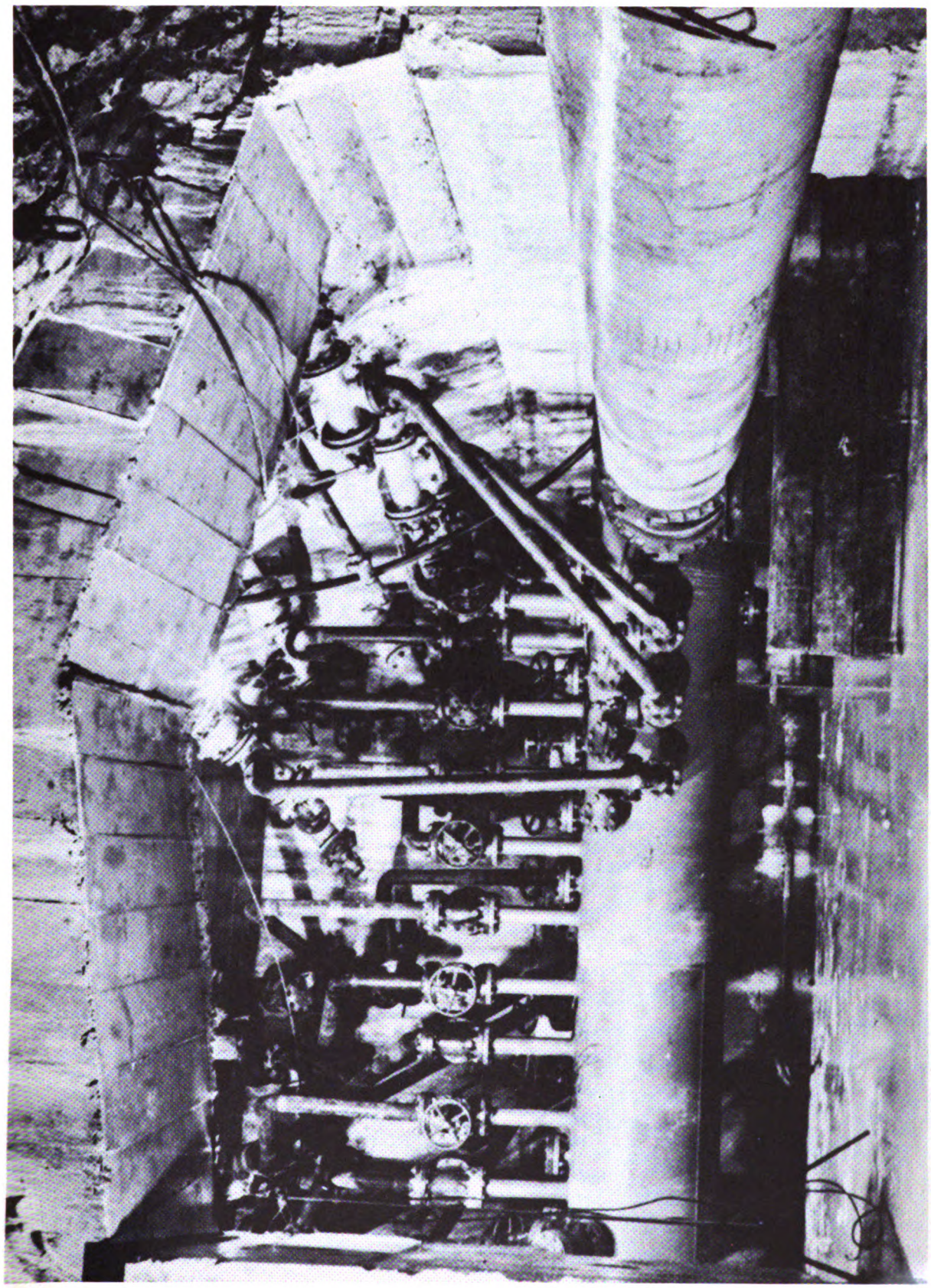

Figure 20. - Manifold for pumping from NX holes on 600-foot level.

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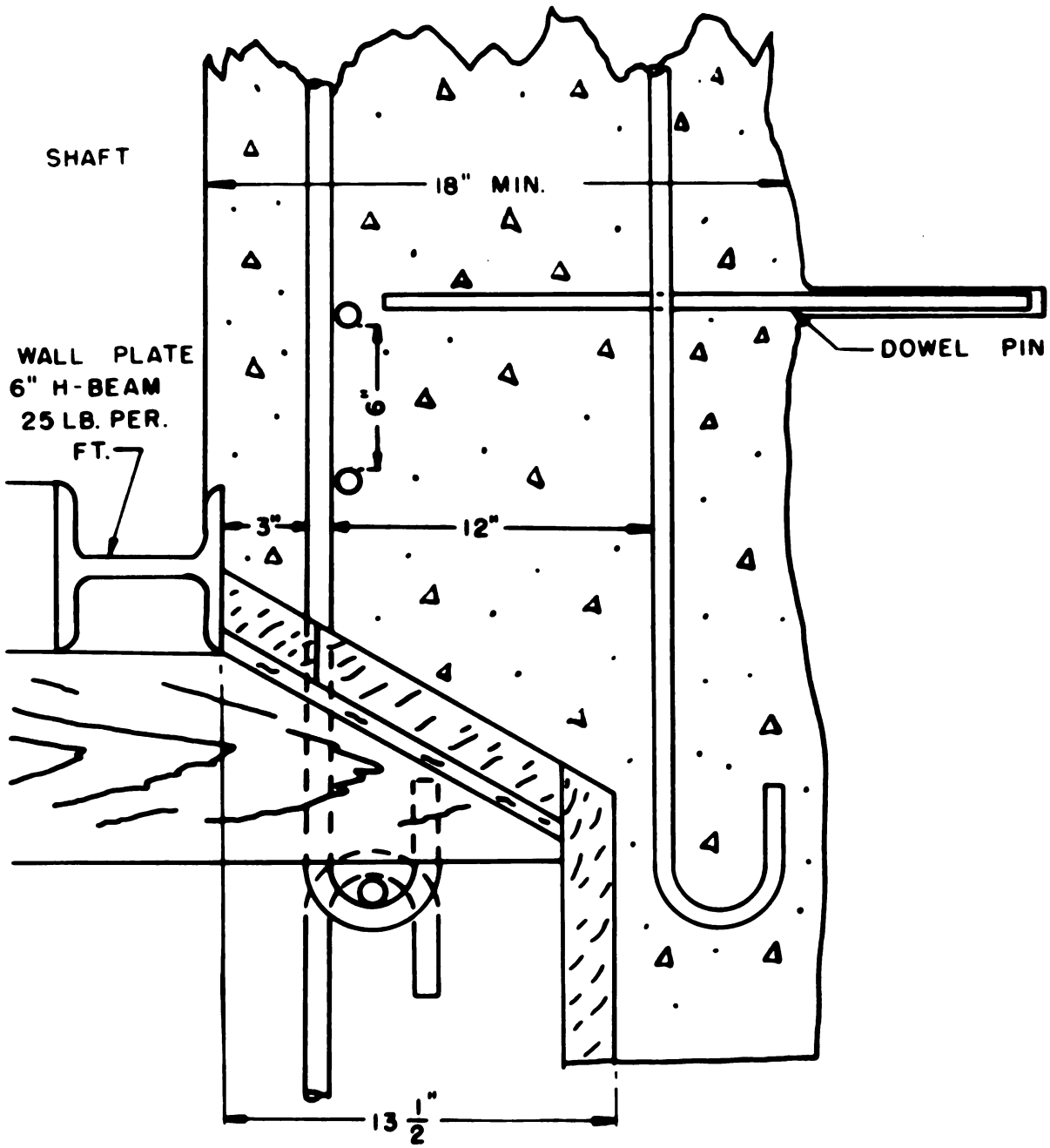

Figure 21. - Concrete construction joint showing reinforcing steel.

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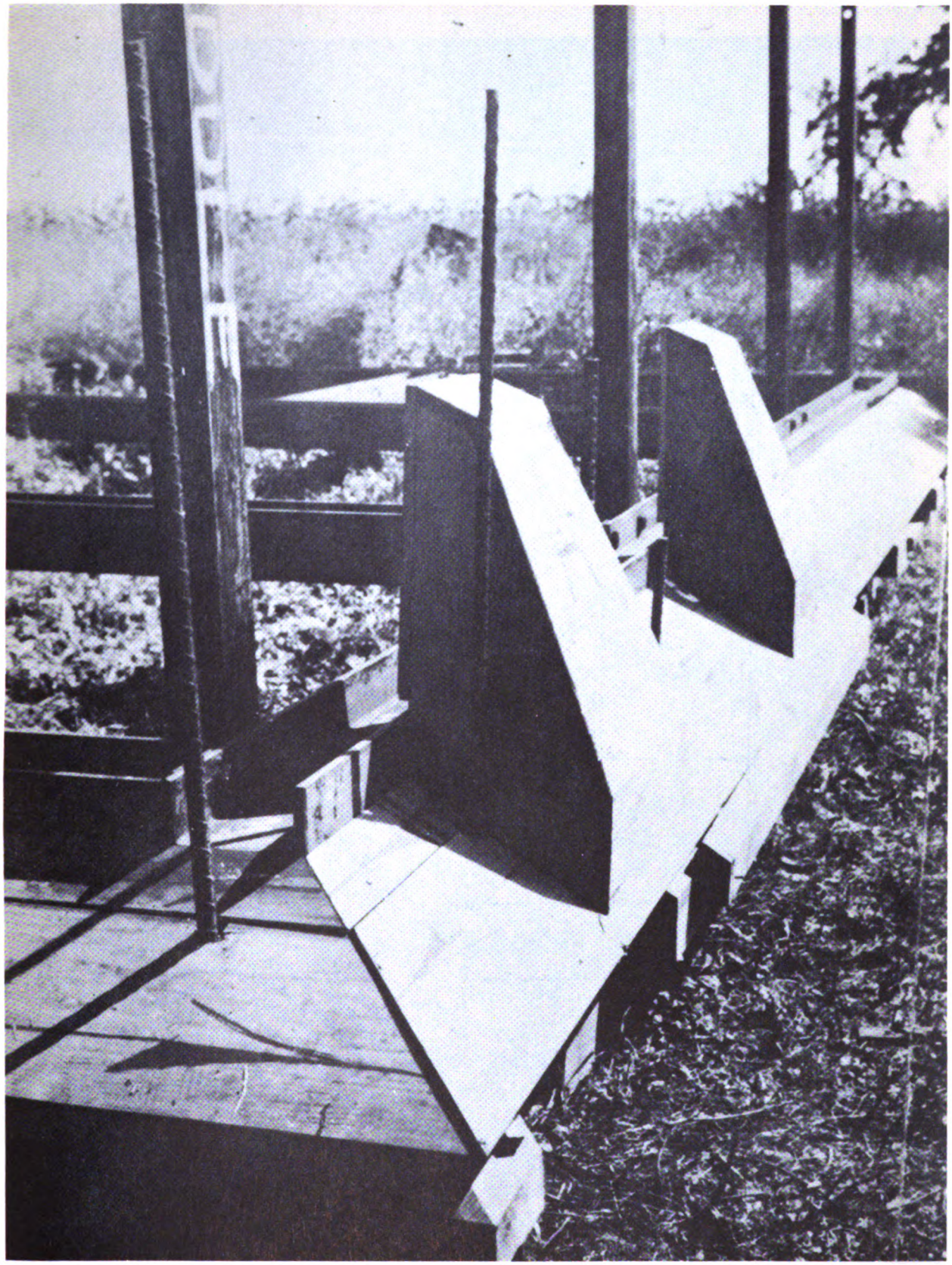

Figure 22. - Flooring and placement boxes of the concrete forms.

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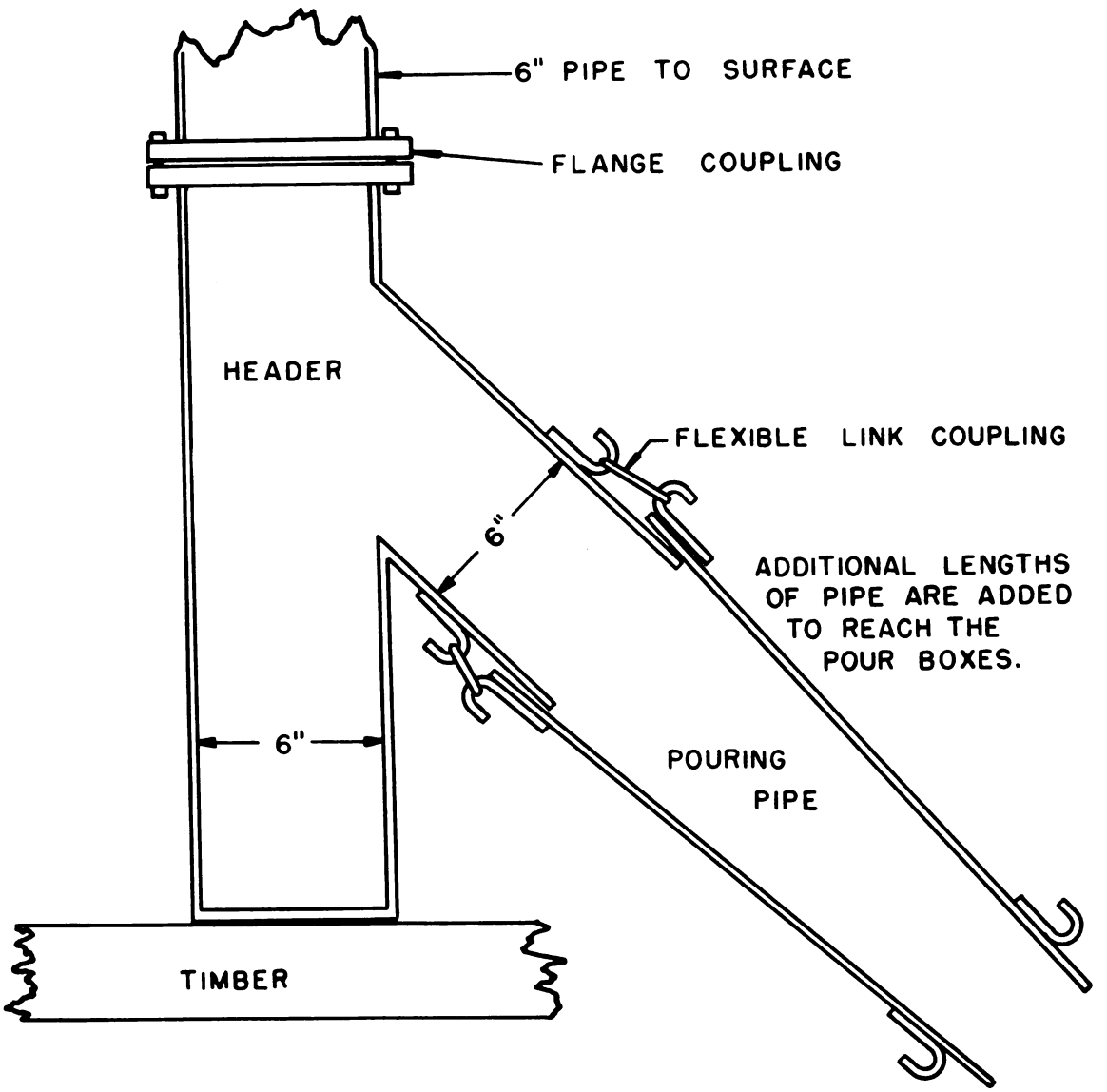

Figure 23. - Concrete placement header.

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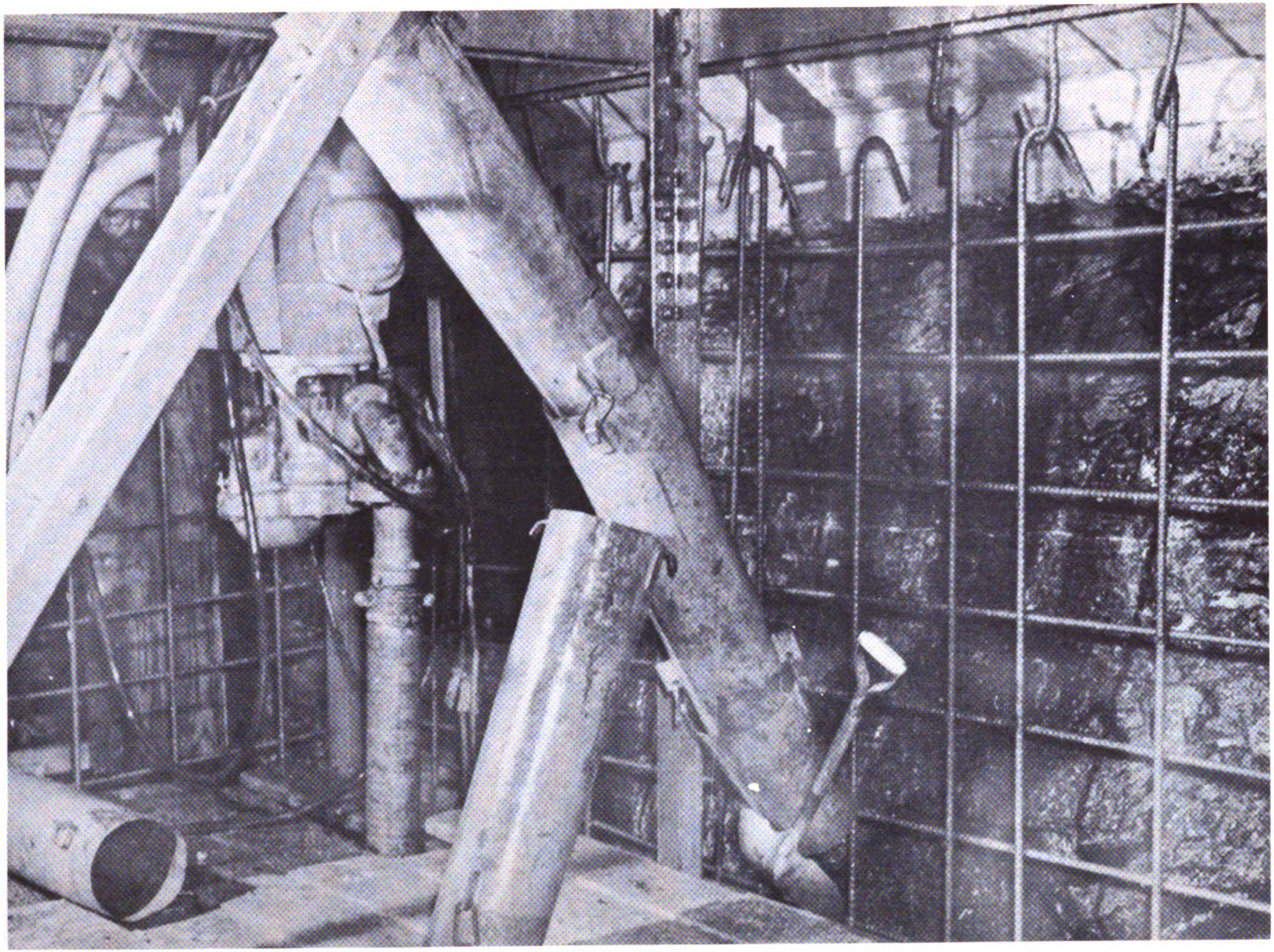

Figure 24. - Placing concrete for the shaft lining.

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Vibrators were used to pack the concrete tightly and eliminate voids. Two hours was required to place a section of concrete lining 7 feet high. The concrete was allowed to set 8 hours, and then another section was placed. The top 7 feet was cast through ducts in the concrete above, which had been formed by the pour boxes at the bottom of the previous section.

Costs

The costs of sinking the shaft in units of labor, supplies, and materials are summarized in tables 2 and 3. Table 4 shows pertinent engineering data, and tables 5 and 6 give breakdowns of labor and material costs on grouting from the surface and from the shaft.

Safety

A very good safety record was achieved by the E. J. Longyear Co. while the shaft was being sunk (table 7). There were no fatal accidents and only 17 lost-time accidents.

TABLE 2. - Labor requirements

Item	Labor, man-hr.	Total man-hr.	Labor per ft. of shaft, man-hr. per ft.
I. Hoisting and landing	72,749	72,749	57.69
II. Surface installations:			
A. Erect sinking headframe	1,455		
B. Dismantle sinking headframe	448		
C. Surface installations, utilities, office operations	67,627	69,530	55.14
III. Permanent work:			
A. Skip roads	3,095		
B. Power cables	1,208		
C. 10-inch airlines	1,400		
D. Counterweight rails	2,403		
E. Permanent man-cage guides	2,334		
F. Man-cage chairs	1,882		
G. 20-inch pumplines	144	12,466	9.89
IV. Excavation:			
A. Drilling	18,596		
B. Blasting and ventilation	7,401		
C. Mucking	43,442		
D. Timbering	4,996		
E. Guides, ladders, screens, etc.	11,089		
F. Delays	6,511	92,035	72.99
V. Concreting:			
A. Forms and reinforcing steel	55,615		
B. Concrete	13,314	68,929	54.66
VI. Test drilling and grouting:			
A. From surface	62,856		
B. While sinking shaft	130,392	193,248	153.25

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TABLE 2. - Labor requirements (con.)

Item	Labor, man-hr.	Total, man-hr.	Labor per ft. of shaft, man-hr. per ft.
VII. Excavation of levels and loading pocket.	58,496	58,496	46.39
VIII. Bulkheads on levels.....	12,444	12,444	9.87
IX. Preparation for lowering water table:			
A. Diamond drilling, 600 level.....	11,335		
B. Other.....	13,626	24,961	19.79
Totals.....		604,858	479.67

TABLE 3. - Material and supply requirements

Item	Amount	Amount per foot of shaft
Concrete:		
Surface installations.....cu. yd.	183	
Shaft collar.....do.	1,173	
Shaft lining.....do.	6,574	
Pads.....do.	111	
Bulkheads.....do.	382	
Ore pocket.....do.	266	
Diamond-drill station, 600 level.....do.	133	
Total.....do.	8,822	7.00
Grout:		
In surface holes.....cu. ft.	135,136	
While sinking shaft.....do.	61,119	
Total.....do.	196,255	155.63
Steel:		
176 shaft sets.....tons	191	
10 Bearer sets.....do.	16	
28 pipe hangers.....do.	14	
Reinforcing steel.....do.	93	
80-lb. rails in skip roads (5,400 ft.).....do.	72	
Permanent air and pump lines (3, 176 ft.).....do.	140	
Temporary ventilation, concrete, grout, pumplines.....do.	132	
Precussion drill steel.....do.	30	
Precussion drill bits (994)		
Total.....do.	688	0.55
Explosives:		
Dynamite, 40-percent:		
In shaft.....pounds	88,725	
In levels and loading pocket.....pounds	41,975	
Total.....do.	130,700	103.65
Electric blasting caps:		
In shaft.....number	21,731	
In levels and loading pocket.....do.	11,532	
Total.....do.	33,263	26.38

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TABLE 4. - Engineering data

	Amount
Excavations	
Shaft.....linear ft.	1,261
Levels.....do.	945
Shaft.....cu. yd.	17,934
Levels and loading pocket.....do.	6,399
Total.....do.	24,333
Concrete lining in shaft.....linear ft.	1,260.5
Test holes	
Preparation from surface.....do.	57,554
While sinking shaft.....do.	117,039
Total.....	174,593
Diamond drilling on 600 level for lowering water table..... linear ft.	7,276
Water seepage after completion of shaft..... gal. per minute	200-300

TABLE 5. - Test drilling and grouting from surface

	Amount
Diamond drillholes.....number	25
Original drilling.....linear ft.	8,677
Redrilling grouted holes.....do.	48,877
Grout.....ccu.ft.	135,136
Cement.....bags (95 lb.)	72,000
Filler (fly ash).....do.	24,000
Sand.....cu. ft.	24,000
Labor.....man-hr.	62,856

TABLE 6. - Test drilling and grouting from shaft

Location	Number of test holes: Diamond drill	Number of test holes: Percussion drill	Footage drilled: Diamond drill	Footage drilled: Percussion drill	Grout, cu.ft.	Concrete, cu.ft.	Crushed rock, tons	Labor man-hr.
From shaft, 0 to 273... feet.....	669	86	27,861	1,917	17,726			31,807
Shaft plugs and pads...					11,012	111	801	13,614
From shaft, 273 ft. to bottom.....	194	1,188	9,576	29,847	2,643			22,952
Shaft leaks.....					1,713			2,014
From station levels....	62	1,643	4,139	26,498	9,262			16,397
From pump levels.....	19	416	1,639	6,447	8,476			6,403
D.D. station, 600 level	41		2,178		614			2,702
Plug on 400 level.....	6		2,334		7,902			18,606
Crouting under and removing 400 level plug	31	92	2,605	1,718	1,771			9,280
From loading pocket....		14		280				116
Installing and removing group pipes.....								6,501
Totals	1,022	3,439	50,332	66,707	61,119	111	801	130,392

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TABLE 7. - Safety record

Disabling (lost-time) accidents.....number	17
Nondisabling accidents .....do.	196
Total accidents.....do.	213
Total man-hours worked.....	619,246
Injury frequency rate[1].....	27.4
Injury severity rate[2].....	0.607

1/ Number of disabling accidents per 1,000,000 man-hours.

2/ Number of days lost per 1,000 man-hours.

Disabling (lost-time) Accidents

Cause	Number	Days lost
Falling rock	1	3
Falling piece of pipe	1	52
Fractures caused by slipping	3	29
Drill falling on hand	1	45
Striking foot while using sinker drill	3	35
Finger injuries while drilling	2	72
Hernias caused by lifting	3	131
Splinter in hand	1	4
Foreign body in eye	2	5
Total	17	376

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